THE ELECTRICAL ENGINEERING
DEPARTMENT OF THE UNITED STATES
AIR FORCE ACADEMY

PROCEEDINGS OF THE 1983 Symposium on Military Space Communications and Operations

★

August 2, 3, and 4
USAF Academy, Colorado

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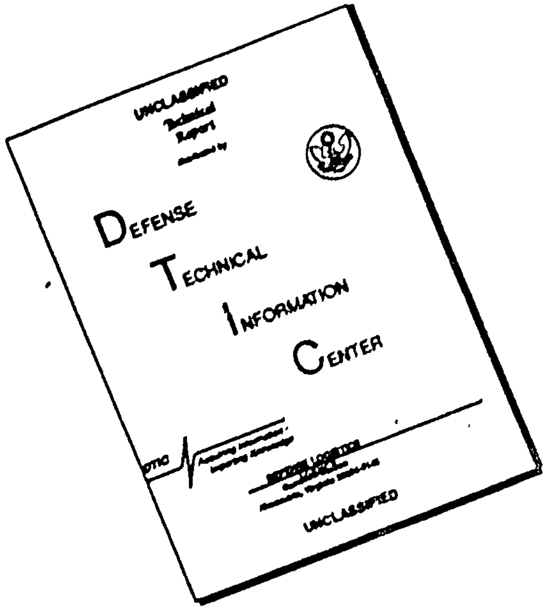

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PROCEEDINGS OF THE

1983 Symposium on Military Space Communications and Operations

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August 2, 3, and 4
USAF Academy, Colorado

1983 Symposium on Military Space Communications and Operations

Sponsored by:

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and
Rocky Mountain Chapter of the Armed Forces Communication Electronics Association

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PREFACE

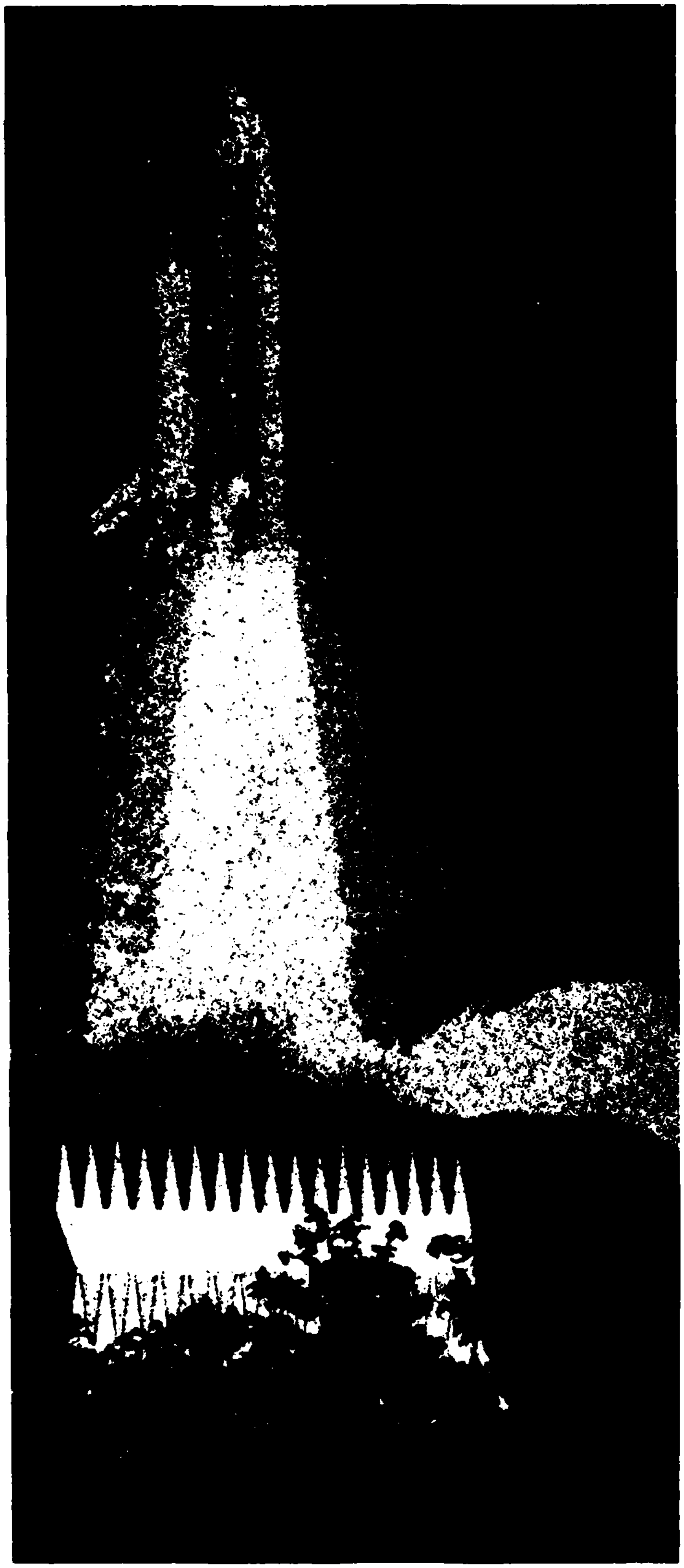
On behalf of the Air Force Academy Department of Electrical Engineering and the Rocky Mountain Chapter of the Armed Forces Communication-Electronics Association, welcome to the 1983 Symposium on Military Space Communications and Operations. Space is our newest dimension of military operations so it is appropriate that this first symposium be held when our newest service Academy is marking the 25th Anniversary of its first graduating class.

This symposium provides a forum where military and industry can gather to discuss the latest developments emerging in military space communications and operations. We have created an environment that simulates social and technical interchange among members of space communications and operations organizations. We are honored to have the foremost leaders of the military and industry space community participate in our first symposium and discuss the latest concepts in this newest dimension.

We appreciate your participation in the first symposium and look forward to your continued interest in space—"The Newest Dimension of Military Operations."

Welcome to Colorado Springs!

GEORGE D. PETERSON
Chairman



Satellite Communications Aircraft Display

Air Force Wright Aeronautical Laboratory

Mr. Allen Johnson, Chief

Satellite Communications Group

Capt Anne Hocutt

1st Lt Mike Shepard

2nd Lt John Holt

Mr. Wayne Fischbach

Mr. Roger Swanson

Raytheon

Mr. Claud Begin

Mr. Bill Brown

Linhabit

Mr. Jim Sheets

Collins

Mr. Bill Rembacz

4950th Test Wing

1st Lt Bob Duffer

2nd Lt Bob Waggoner

Air Force Wright Aeronautical Laboratory (AFWAL)

Satellite Communications Test Aircraft

The AFWAL Satellite Communication Test Aircraft is an Air Force C-135 (Boeing 707) aircraft assigned to the 4950th Test Wing at Wright-Patterson AFB, Ohio. The aircraft is configured to test communications satellite equipment in either a point-to-point or loop-back mode.

The aircraft is currently configured to test the AN/ASC-30 EHF/SHF dual band Command Post Satcom Terminal. The AN/ASC-30 was developed by Raytheon for the Air Force Wright Aeronautical Avionics Laboratory. The AN/ASC-30 is intended for E4-B, EC-135, and other Airborne Command Post type Aircraft as well as for ground fixed and mobile command posts.

The Satellite Communications Test Aircraft is available for tours from 4:00-6:00 p.m. 3 August at Peterson AFB.

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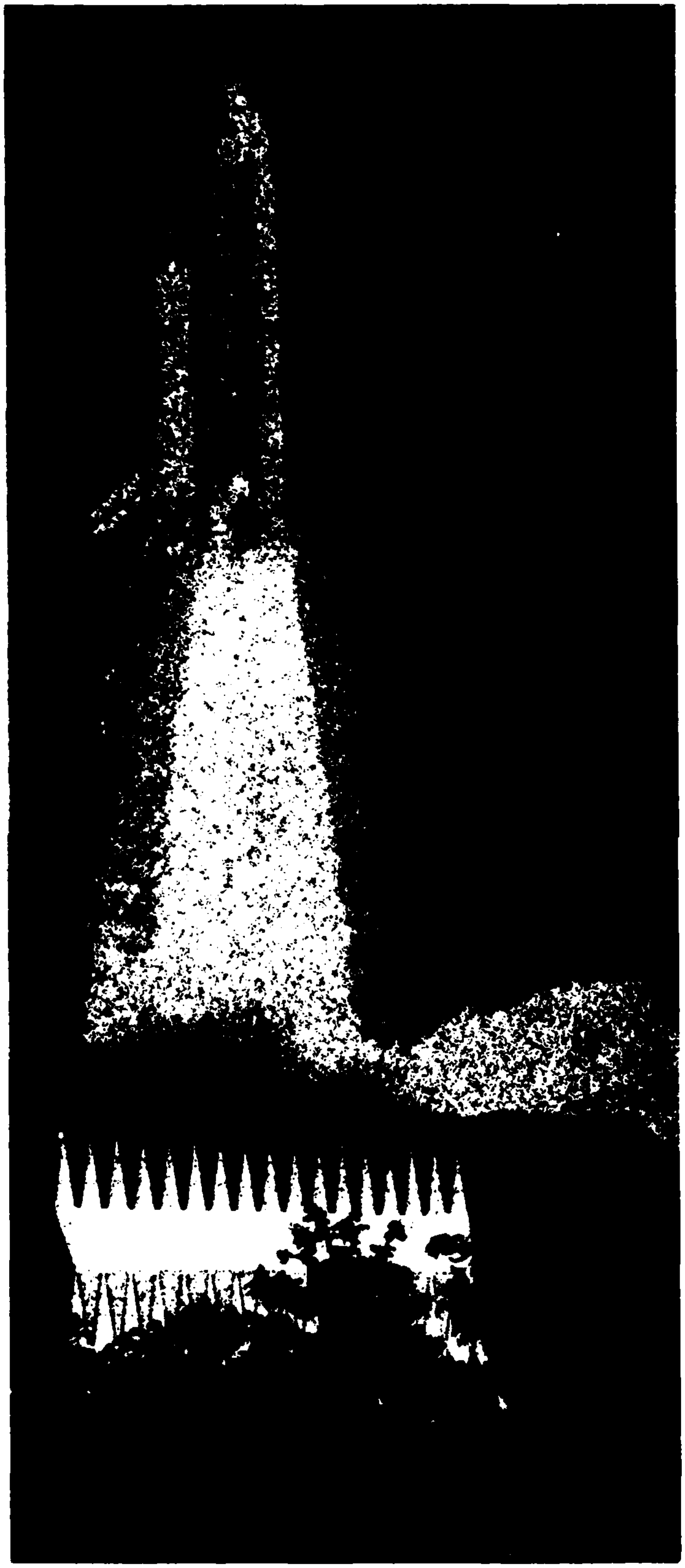
†Manuscript not available for publication.



Panel Discussion

Space: The New Dimension of Military Operations

Panel Moderator

LT GEN WILLIAM J. HILSMAN, USA
Director, Defense Communications Agency

Panel Members

LT GEN LEE M. PASCHALL, USAF (Ret.)
President, American Satellite Company

HENRY B. STELLING, JR.
Vice President, Requirements Analysis and Programs

COL WAYNE SCHRAMM, USAF
Director, Information Systems
HQ USAF

DR. ALBERT P. BRIDGES
President, Kaman Sciences Corp.

MAJ GEN WINSTON D. POWERS, USAF
DCS/Comm, Electronics and Computer Resources, Space Command

Panel Moderator

Lt Gen William J. Hilsman, USA
Director
Defense Communications Agency

Lieutenant General William J. Hilsman is the Director, Defense Communications Agency (DCA). As Director, General Hilsman has a broad range of responsibilities including: management and direction of the Worldwide Defense Communications System; system engineering and technical support to the National Military Command System; the provision of technical support to the Worldwide Military Command and Control (WWMCC) System, and numerous other responsibilities such as providing analytical and automated data processing support to the Joint Chiefs of Staff. The Director, DCA also acts in several other capacities. As Manager, National Communications System, he is responsible for providing direction to the Worldwide National Communications System, which includes the communications facilities of the various Federal Agencies. In his capacity as Director, WWMCC System Engineer, he is responsible for providing integration and technical guidance for the implementation of architecture and technical evolution of the Worldwide Military Command and Control System. The Director, DCA is also Chairman, Military Communications-Electronics Board, which provides a liaison point for joint and international communications matters.

Lieutenant General Hilsman was born in St. Louis, Missouri, on 13 March 1932. He graduated from the United States Military Academy in 1954 and was commissioned as a second lieutenant. He earned a Master's Degree in Electrical Engineering from Northeastern University, and is a graduate of the Army Command and General Staff College and the Industrial College of the Armed Forces.

Upon graduation from the Army Command and General Staff College in July 1966, General Hilsman was assigned as Executive Officer, 121st Signal Battalion, 1st Infantry Division, Pacific-Vietnam.

He returned to the United States in August 1967 and served as Signal Systems Plans Officer, Office, Assistant Vice Chief of Staff until July 1968. In August 1968 he assumed the duties of Chief, Research Team, Information Sciences Group, Management Information Systems Directorate, Office, Assistant Vice Chief of Staff until July 1969.

General Hilsman served as Commanding Officer of the 144th Signal Battalion, 4th Armored Division, United States Army, Europe until February 1971, when he was selected to attend the Industrial College of the Armed Forces in July 1971. Upon graduation from the Industrial College of the Armed Forces in June 1972, General Hilsman was assigned as Chief, Training Support Division, later President, United States Army Combat Arms Training Board, and later Special Assistant to the Deputy Chief of Staff for Training and Schools, United States Army Training and Doctrine Command, United States Army Infantry Center, Fort Benning, Georgia.

In December 1973 General Hilsman assumed command of the 1st Signal Group, Fort Lewis, Washington and served in that position until reassignment in June 1975 to Fort Monmouth as Project Manager, Army Tactical Data Systems (ARTADS) and also provisional commander of the Army Communications Research and Development Command (CORADCOM).

General Hilsman commanded the United States Army Signal Center and Fort Gordon from 1977 to 1980. He was also Commandant of the United States Army Signal School.

General Hilsman's decorations include the Meritorious Service Medal, Legion of Merit with 2 Oak Leaf Clusters, Bronze Star Medal with 2 Oak Leaf Clusters and the Army Commendation Medal with Oak Leaf Cluster.

He is married to the former Emily Jean Butler. They have four children.

Panel Member

Lt Gen Lee M. Paschall, USAF (Ret.)
President
American Satellite Company

General Paschall was born in 1922 at Sterling, Colorado. He graduated from Phoenix Union High School, attended the University of Colorado, graduated from the University of Alabama with a Bachelor of Arts degree in History (Phi Alpha Theta, Phi Beta Kappa) and graduated from George Washington University with a Master of Arts degree in International Affairs. He is a graduate of the Infantry Officer Candidate School and the Infantry Communications Officer School, Fort Benning, Georgia; Air Command and Staff College, Communications-Electronics Staff Officer School; and a distinguished graduate of the Air War College, Maxwell Air Force Base, Alabama.

He rose through the ranks from Private to Lieutenant General, having been a member of the Arizona National Guard, the Colorado National Guard and the United States Army before and during World War II. Thereafter, he was the communications engineer for the Colorado Air National Guard until recalled to active duty with the United States Air Force in 1951. Subsequent assignments included Director of Operations, 159th Aircraft Control and Warning Group; Director of Operations 1815th Airways and Air Communications Group; Staff and Faculty, Air University; Chief, Signals Coordination Division, Allied Forces Central Europe (NATO); Office of Commercial Communications Management, Air Defer [illegible]ommand; Defense Commercial Communications Offi[illegible]A; and Headquarters, Defense Communications Ag[illegible] He served as Commander, United Kingdom Comm[illegible]s Region (AFCS), Deputy Director then Director of C[illegible]d, Control and Communications, Headquarters United S[illegible]s Air Force and for four years as the Director of the Defense Communications Agency and Manager of the National Communications System, retiring on 1 August 1978. He was an independent consultant to industry and government on telecommunications and information systems until assuming his present position as President and Chief Executive Officer of American Satellite Company on 3 August 1981.

General Paschall's decorations include two Distinguished Service Medals and the Legion of Merit with one oak leaf cluster.

General Paschall and his wife, Bonnie, reside at 1083 Pensive Lane, Great Falls, Virginia, and their family consists of Patricia (Paschall) Grillos, her husband John and children, Christina and Stephen, of Belmont, California; Mary and Stephen Paschall and their son, Brian, of Boulder, Colorado; and David Paschall of Annandale, Virginia.

Panel Member

Henry B. Stelling, Jr.
Vice President
Requirements Analysis and Programs

Henry B. Stelling, Jr. is Vice President of Requirements Analysis and Programs for Rockwell International Corporation's Defense Electronics Operations (DEO), having been named to that post in May 1980.

His responsibilities support strategic business planning and analysis specifically related to U.S. and international requirements for defense electronic systems. This includes an assessment of mission area needs, projected system vulnerabilities, and alternative system concepts.

Currently, Mr. Stelling also has responsibility for managing the payload proposal for the Space Based Space Surveillance System. This effort is directed toward the development of system concepts for a long-wave infrared prototype capable of detecting and tracking other space objects at extremely long range.

Headquartered in Anaheim, California, DEO is recognized in the defense electronics community as a leader in guidance and navigation; command, control, and communications; and intelligence programs. DEO is also developing a key role in tactical weapons systems, electro-optics, shipboard electronics systems, and electronic warfare in both domestic and international markets.

Prior to assuming his post with Rockwell International, Stelling was a major general in the U.S. Air Force, with his last assignment as Vice Commander, Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts.

During his military career, Stelling held assignments with the Armed Forces Special Weapons Project at Sandia Base, New Mexico; Directorate of Special Weapons at Tactical Air Command Headquarters, Langley Air Force Base, Virginia, 384th Bombardment Wing of the Strategic Air Command at Little Rock Air Force Base, Arkansas; Air Force Systems Command at the Space and Missile Systems Organization in Los Angeles, California; and Director of Space in the Office of the Deputy Chief of Staff for Research and Development at Headquarters U.S. Air Force.

A native of San Francisco, Stelling attended the School of Engineering at the University of California, Berkeley, where he was when called up for active duty in 1943 with the U.S. Army Enlisted Reserve Corps. In 1944, he entered the U.S. Military Academy, graduating in 1948 with a bachelor of science degree in engineering and a commission as a second lieutenant in the U.S. Air Force. While on active duty, he subsequently received a master's degree in business administration from the University of California, and a master of science degree in international affairs from George Washington University.

He is also a graduate of the Armed Forces Staff College and the National War College.

Stelling is a member of Beta Gamma Sigma business administration fraternity and a number of defense associations. He is active in community affairs as a board member of the United Way of Orange County North/South.

Panel Member

Col Wayne E. Schramm, USAF
Director
Information Systems, HQ USAF

Colonel Wayne E. Schramm is the Deputy Director of Command and Control, and Telecommunications, in the office of the Deputy Chief of Staff, Plans and Operations, Headquarters United States Air Force.

The Directorate of Command and Control, and Telecommunications has the overall responsibility for communications in the Air Force, and is also the office of primary responsibility for programmatic and budget activities related to operational command and control, and communications systems.

Col Schramm was born in Howard, South Dakota on 3 May 1936, graduated from Howard High School in 1954, and South Dakota State College in 1958 with a Bachelor of Science Degree in Engineering Physics and an Air Force Reserve Officer Training Course Commission.

Colonel Schramm was first assigned duties as a Tactical Officer for Cadets at Lackland Air Force Base, Texas, and completed the Basic Communications-Electronics Course at Keesler Air Force Base, Mississippi, in 1959.

In October 1959 Col Schramm was assigned to the Fifth TAC in the Philippines, where he planned and participated in exercise deployments in Japan, Korea, Okinawa, Thailand and Taiwan.

Upon returning to the CONUS in 1961, Colonel Schramm was assigned to the 1911th Comm Squadron at Offutt Air Force Base, Nebraska. At Offutt, he was the Chief of Maintenance and Comm Operations Officer.

Colonel Schramm's next assignment was on the Comm Staff of Headquarters Fifth Air Force, Fuchu Air Force Station, Japan, where he managed Comm Operations in Korea and Okinawa as well as Japan. While in Japan he also obtained a Master's Degree in Aerospace Management from the University of Southern California.

In November 1967 Col Schramm returned to the United States to attend Air Command and Staff College. Following his graduation, he was assigned as Commander of the 506th Tactical Control Maintenance Squadron at Udorn, Thailand.

Upon his return to the United States in 1969, Col Schramm commanded Det 5, AFCS, the AFCS Liaison Office to ESD at Hanscom Air Force Base, Massachusetts.

After attending the Communications-Electronics Staff Course at Keesler Air Force Base, Mississippi, in 1971, Colonel Schramm was assigned to Headquarters United States Air Force, Office of Deputy Chief of Staff, Programs and Resources, where he worked communications-electronics programs and communications-electronics doctrine.

In 1975 Colonel Schramm left the Air Staff to attend the National War College, graduating in 1976. Colonel Schramm was then assigned as the Vice Commander and subsequently Commander of the 1945th Communications Group at Rhein Main Air Base, Germany. In 1979 Colonel Schramm returned to the Air Staff as Chief of the Tactical C3, Navigation and Automation Division and later Chief of the Strategic Command, Control and Communications Division in the Directorate of Space Systems and Command, Control and Communications, Deputy Chief of Staff, Research, Development and Acquisition, Headquarters United States Air Force.

In July 1982 Colonel Schramm assumed his present duties as Deputy Director of Command and Control, and Telecommunications, Deputy Chief of Staff, Plans and Operations, Headquarters United States Air Force.

Colonel Schramm's military decorations and awards include the Bronze Star, the Meritorious Service Medal with one Oak Leaf Cluster, and the Air Force Commendation Medal with two Oak Leaf Clusters.

Colonel Schramm is married to the former Jean McClure of Mobile, Alabama, and has two children, Susan, 19, and Judy, 14. Colonel Schramm was promoted to the grade of Colonel with a date of rank of 30 August 1977.

Panel Member

Dr. Albert P. Bridges
President
Kaman Sciences Corp.

Dr. Bridges has been President of Kaman Sciences Corporation since August 1972 and is Group Head of Kaman Corporation's Science group. He has over thirty-one years' experience in the management of high-technology companies and programs as well as technical experience covering experimental investigations, analytical and theoretical studies, and engineering and technical activities.

As a member of Kaman's senior management team since 1957, Dr. Bridges has worked extensively in the areas of high-technology management, new product concepts, systems/operations analysis, nuclear weapons effects, missile technology, and inertial distance systems. Throughout the period 1957-1969 he was responsible for technical direction of U.S. Navy projects at Kaman for the POLARIS and POSEIDON missile systems.

As a Project Engineer for Aerophysics Development Corporation prior to his joining Kaman, Dr. Bridges was responsible for all instrumentation, flight tests, and data analyses on the flight test vehicle programs. At Sandia Corporation, Dr. Bridges conducted investigations pertaining to arming and fuzing, inertial distance systems, new weapons concepts, and the energy absorbing characteristics of inelastic solids during dynamic loading.

Dr. Bridges received his Ph.D. (1951) and M.S. (1950) degrees in Physics from Vanderbilt University and his B.S. (1947) in Physics from the University of the South.

Dr. Bridges is a senior member of the Institute of Electrical & Electronics Engineers (IEEE), American Physical Society (APS), American Association of Physics Teachers (AAPT), Association of Astronautical Society (AAS), American Phylatelic Society, and a Registered Professional Engineer in the State of Colorado.

Community and professional activities include: 1981-1983—Member of Chancellor's Advisory Council for University of Colorado-Colorado Springs; 1982—President of North End Commercial Association; 1981-1983—Member of the Energy, Environment & Transportation Steering Committee for the City of Colorado Springs Chamber of Commerce; 1980-1981—Member of Business Advisory Council for University of Colorado—Colorado Springs; 1980-1981—Board of Director for North End Commercial Association; 1980—Member of Governor Richard Lamm's "Energy, Environment & Natural Resources Committee" reviewing the energy requirements of Colorado's Front Range area; 1977-1980—Board of Director for the City of Colorado Springs Chamber of Commerce; 1977—Advisor on the U.S. Department of Energy's Technology Study Panel for the Inexhaustible Energy Resources Study; 1975-1976—Chairman of the American Electronic Association—Colorado Council; and 1974-1976—Director of the American Electronics Association.

Panel Member

Maj Gen Winston D. Powers, USAF
DCS/Comm, Elects and
Computer Resources, Space Command

Major General Winston D. Powers is deputy chief of staff, communications, electronics and computer resources for the U.S. Air Force Space Command (SPACECOM) and the North American Aerospace Defense Command (NORAD); chief, Systems Integration Office, Space Command; and commander of the Space Communications Division, Air Force Communications Command (AFCC), with consolidated headquarters located at Peterson Air Force Base, Colo.

General Powers was born Dec. 19, 1930, and hails from Brooklyn, N.Y. He has a bachelor of arts degree from McKendree College, Ill. He attended graduate school at The George Washington University and completed the Industrial College of the Armed Forces.

He began his military career by enlisting in the U.S. Air Force in November 1950. His first assignment was with the Air Defense Command at Hancock Field, N.Y. He entered navigator training at Ellington Air Force Base, Texas, in September 1952, and graduated the following year. He then had B-29 crew training at Randolph Air Force Base, Texas, before an assignment as a navigator instructor at Ellington Air Force Base.

In May 1957 General Powers entered the Tactical Communications Officer Training School at Scott Air Force Base, Ill. After graduation in June 1958, he was assigned as commander of the 314th Air Division Early Warning Radar Station, Cheju, Korea. He then returned to Scott Air Force Base in June 1959, for duty with the 1918th Communications Squadron.

Following graduation from McKendree College in August 1961, General Powers was assigned to the Air Force Command Post at the Pentagon as a communications officer. In July 1963 he was selected to attend the Communications Systems Engineering Program of the American Telephone and Telegraph Company in New York City. After completing the AT&T Education-With-Industry program, he was assigned as communications engineer for the Defense Communications Agency-United Kingdom, at Croughton, England.

In August 1967 the general was transferred to the Tactical Communications Area, Langley Air Force Base, Va., as director of tactical communications operations and then as director of fixed communications operations. He returned to a flying assignment in July 1970, with the 460th Reconnaissance Wing at Tan Son Nhut Air Base, Republic of Vietnam, flying 75 combat missions in EC-47s.

He was assigned to the Organization of the Joint Chiefs of Staff in July 1971, as the Air Force member of the Plans and Policy Division. In October 1973 General Powers was reassigned to Headquarters U.S. Air Force, Washington, D.C., as special assistant for joint matters in the Directorate of Command, Control and Communications, Office of the Deputy Chief of Staff, Programs and Resources.

General Powers returned to Korea in February 1974, as commander of the 2146th Communications Group and director of communications-electronics for the 314th Air Division at Osan Air Base. He returned to Air Force headquarters in November 1974, as chief, Plans and Programs Division, Directorate of Command, Control and Communications, where he also served as chairman of the Command, Control and Communications Panel, and later as a member of the Program Review Committee of the Air Staff Board.

The general became deputy director of telecommunications and command and control resources, Office of the Assistant Chief of Staff, Communications and Computer Resources at Air Force headquarters in September 1975, and director in June 1978. He was appointed deputy director of command, control and communications at the headquarters on July 1, 1978. He assumed his positions for NORAD in October 1978, and for Space Command on Sept. 1, 1982. General Powers became the first Space Communications Division, AFCC, commander on January 1, 1983.

The general is a master navigator with more than 4,000 flying hours. His military decorations and awards include the Legion of Merit, Meritorious Service Medal with two oak leaf clusters, Air Medal with one oak leaf cluster, Air Force Commendation Medal, Presidential Unit Citation emblem and the Outstanding Unit Award ribbon. General Powers was awarded the Eugene M. Zuckert Award, the Air Force's top management award, for 1982.

He was promoted to major general July 1, 1981, with date of rank Sept. 1, 1977.

General Powers is married to the former Jeanette Wyche of Brooklyn, N.Y. They have two children: Diane and David.

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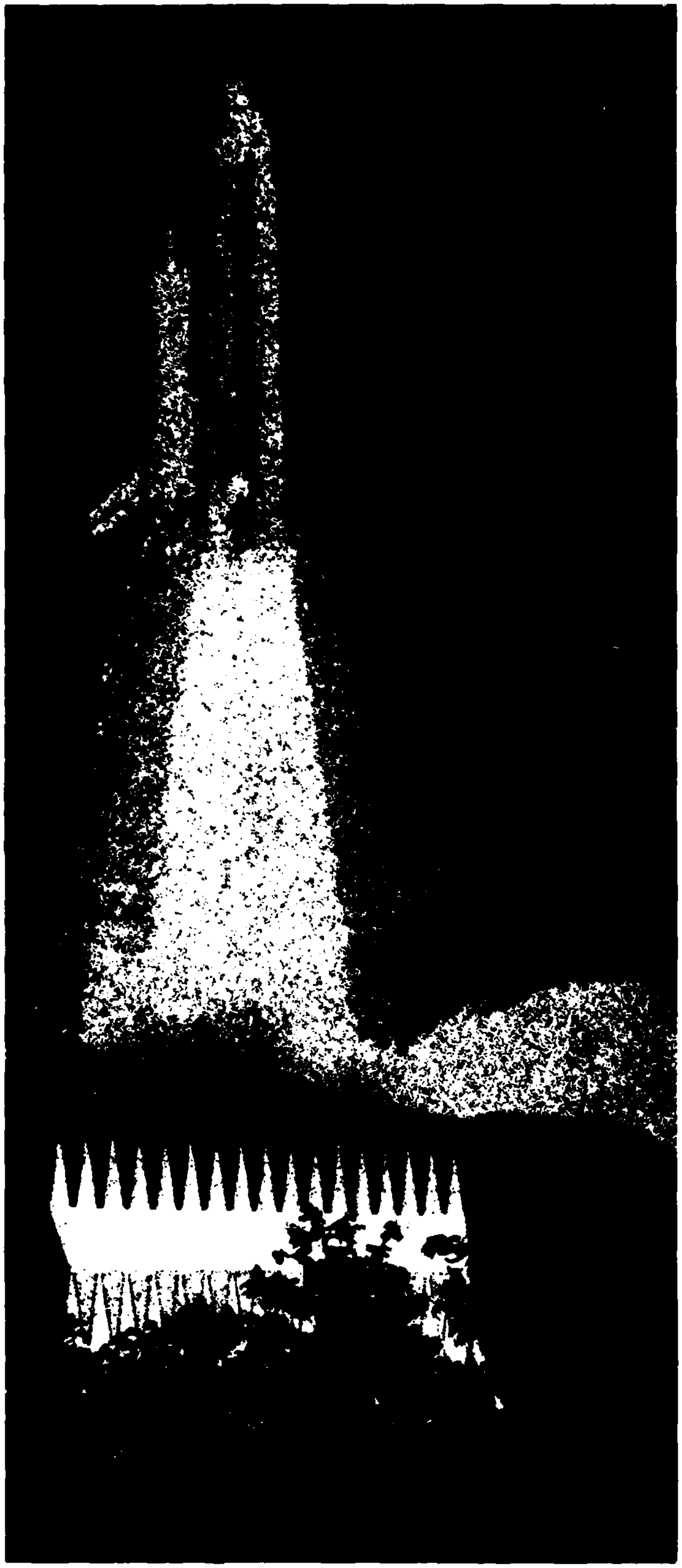

Technical Program

1. Operational Concepts/Missions
2. Network Control/Architecture
3. Space System Survivability/Reliability
4. Space System Technology/Analysis
5. DoD Command and Control Centers
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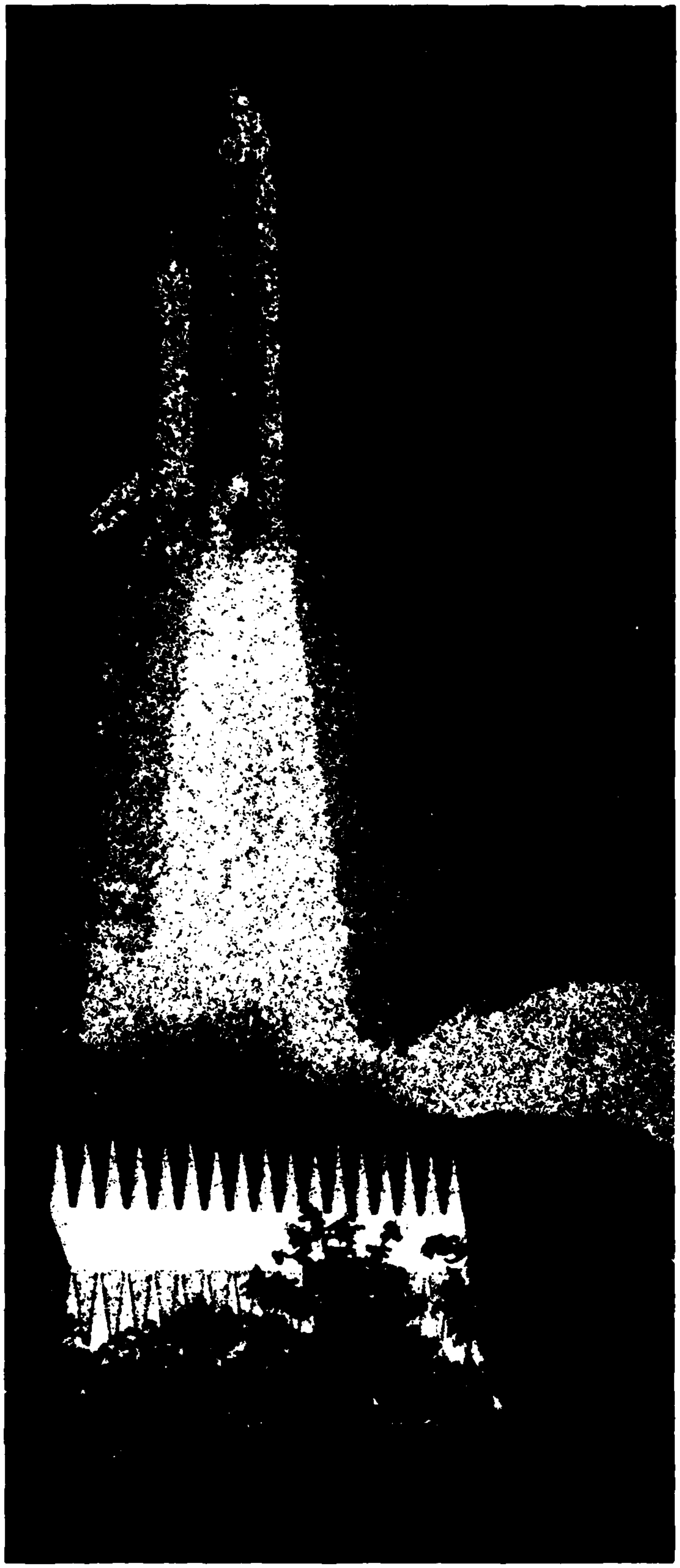


Session 1

Operational Concepts/Missions

Session Chairman: Col. P. Davis, *AFCC/XOS*

The Papers

AIR FORCE SATELLITE COMMUNICATIONS (AFSATCOM) SYSTEM

JACK D. MILLER

HEADQUARTERS STRATEGIC COMMUNICATIONS DIVISION

The AFSATCOM system was developed to provide secure, reliable, survivable, two-way worldwide record communications for command and control of strategic forces. The primary mission of AFSATCOM is Emergency Action Message (EAM) dissemination for the Single Integrated Operations Plan (SIOP) forces. AFSATCOM also provides for the Commanders-in-Chief (CINC) internetting with the National Military Command System, CINC force direction and force report-back. In addition to these communications, AFSATCOM provides service to a number of high priority non-SIOP users, including Presidential support.

The space segment of the AFSATCOM system consists of transponders aboard various host spacecraft. The FLEET SATELLITE COMMUNICATIONS (FLTSATCOM) system satellites in geostationary orbits and the Satellite Data System (SDS) satellites in polar orbits carry the AFSATCOM transponders. This system operates in the military Ultra-High Frequency (UHF) spectrum 225-400MHz and provides a 100 word-per-minute teletype capability. A certain degree of anti-jam protection also has been built into these transponders.

The terminal segment of AFSATCOM consists of a family of modular UHF ground and airborne terminals. Some of the larger ground terminals have been installed in order to maintain worldwide connectivity; these terminals are located at OFFUTT AFB, NE., RAF MILDENHALL, UK., KADENA AB, JA., and EIELSON AFB AK. These terminals are positioned such that they can see two FLTSATCOM satellites and the SDS satellites at any one given time. The Minuteman Launch Control Centers are provided with AFSATCOM terminals. The airborne segment includes AFSATCOM installations in the E-4B, FB-111, EC-135, and B-52G/H models.

The FLTSATCOM satellites made by TRW are positioned over CONUS, the Atlantic Ocean, and the Pacific Ocean, and provide global coverage from 75 degrees North and South latitudes. A total of five satellites have been launched between 1978-81 with four remaining operational. Three more FLTSATs have been purchased, and projected launch dates are mid to late 1980's.

The SDS satellites, made by Hughes Inc., provide 24 hour polar coverage to approximately 40 degrees north latitudes.

These airborne terminals, as well as selected portions of the ground terminals have been provided with Electromagnetic Pulse (EMP) protection. The space segment is also EMP hardened.

The AFSATCOM system remains the most survivable two-way communications system deployed.

AD P002145

SATELLITE TACTICAL COMMUNICATIONS AT HIGH LATITUDES

Lieutenant(Navy) K.L. Matheson

NATIONAL DEFENCE HEADQUARTERS
OTTAWA, CANADA

ABSTRACT

Canada spans about 90 degrees of longitude and has requirements for tactical command and control communications as far north as to at least 84 degrees north latitude. These facts create unique problems when considering requirements for communication by satellite relay. The trend in military satellite communication for tactical purposes is towards the EHF spectrum. For currently practical power aperture levels geostationary EHF satellite communications are not considered likely to be militarily reliable for a country with high latitudes such as Canada. This paper examines the use of inclined elliptic semi-synchronous orbits to solve this problem. It is concluded that a highly elliptic inclined semi-synchronous orbit possesses significant advantages for EHF tactical communications at latitudes common to military operations in the Arctic.

INTRODUCTION

Canadian Forces (CF) satellite communications requirements involve extreme northern latitudes which cannot be covered from a geostationary orbit. A satellite orbit constellation commonly utilized by both the USSR and the US Department of Defense to achieve worldwide northern hemispheric coverage is a 12 hour (period) Molniya orbit constellation.

Since Canada, like the USSR, is a country, occupying over 80 degrees of longitude at a much more northern latitude than the USA, it is considered essential that Canada examine a Molniya type orbit for a Department of National Defence (DND) communications satellite constellation.

AIM

The aim of this paper is to examine and present some of the considerations involved in the utilization of a Molniya orbital constellation for satellite communications for the Canadian Forces.

APPROACH

This paper will initially present a description of Molniya orbits, followed by a review of the implications of the Molniya orbits with respect to Canadian and worldwide coverage. Some technical issues are then raised on the design requirements with a Molniya orbit on the user terminals, the control station, and the satellite.

ORBITAL CHARACTERISTICS

A satellite in a Molniya orbit is characterized by the orbital parameters in the following range:

inclination	(i)	= 63 degrees
period	(p)	= 11 hrs, 57 min, 46 sec
eccentricity	(e)	= .74
arg. of perigee	(w)	= 288.4 degrees
right ascension	(Ω)	= dependent upon preferred east/west location of ground trace.

The above orbital parameters have been selected for specific reasons, as discussed below.

Inclination.

Elliptical orbits are characterized by a rotation of the *line of apsides*. With this orbital perturbation, which is largely due to the oblateness of the earth, the major axis of an elliptical trajectory will rotate in the direction of motion of the satellite if the orbital inclination is less than 63.4 degrees, and opposite to the direction of motion for inclinations greater than 63.4 degrees. Figure 1 presents the apsidal rotation

rate versus inclination angle for various altitudes. Figure 2 shows the velocity requirement per day necessary to correct for apsidal rotation. If the location of the apogee (or perigee) of a given elliptical orbit is desired to be fixed geographically, then either an inclined orbit close to 63.4 degrees must be selected, or stationkeeping fuel will have to be expended to fix the apogee (or perigee) for non 63.4 degree inclinations.

Period.

This orbital parameter is, of course, dependent upon the apogee and perigee altitudes of the orbit. To reduce ground station/user terminal tracking requirements and to make them repetetive (but not immobilize them as for a geostationary satellite) an orbit that gives an integral number of revolutions during the twenty-four hour rotation time of the earth is selected. This is necessary for the satellite ground trace to exactly repeat itself. Since an elliptical satellite orbit, with a period that is integrally divisible into 24 hours, will have a tendency to geographically "hang" over a chosen area on the earth, the greater the satellite period, the longer the "hang", and the less the satellite relative motion (and thus reduced ground station/user terminal tracking rate). A 24 hour, elliptical orbit was examined in the paper "The Tundra Orbit" (1). In addition the value of a "Tundra Orbit" was mentioned the in Canadian Astronautics Limited (CAL) Polarsat study, page 23, 2nd para (2) and alluded to in an Aviation Week and Space Technology article (3). Figure 3 shows a typical "Tundra" ground trace.

In the "Tundra Orbit" study, the inclined elliptical 24 hour period is compared to the inclined elliptical 12 hour period. There are advantages and disadvantages to both orbits, and this paper will not readdress that issue.

The period of the satellite can also be optimized to reduce the rotation of the line of nodes. The nodal regression is caused by the earth's oblateness, and is a rotation of the plane of the trajectory about the earth's axis of rotation at a rate which depends on both orbital inclination and altitude. For example, the successive ground tracks of posigrade circular orbits are farther to the west than would be the case due to earth rotation alone. Figure 4 and 5 give the nodal regression rate versus inclinations for various values of average altitude. Figure 6 shows the velocity required to maintain zero nodal regression. To reduce this velocity requirement (i.e. station keeping fuel requirement), a period can be selected that will exactly compensate for this nodal regression. Both Soviet and American satellites in Molniya type orbits have done this, and a period similar to a typical Soviet Molniya has, for the analysis in this paper, been chosen.

Eccentricity.

The selection of the eccentricity determines the altitude of the apogee and perigee of the satellite orbit. The greater the eccentricity, the more elongated the ellipse and thus the longer the "hang" time when the satellite approaches apogee. This also results in greater satellite intervisibility and communications between two widely separated earth staions. It is also desireable to choose a perigee that is above the atmospheric drag. In addition it may be desireable to optimize the perigee altitude and orbital path to and from perigee, to a less radiation intensive region of the Van Allen belt.

Argument of Perigee.

The selection of this parameter determines the latitude of the satellite's apogee and perigee. (i.e. how far north/south is apogee/perigee?). It is logical for Canada to place the apogee as far north as possible to optimize northern coverge. Thus one could examine an argument of perigee of 270 degrees which places the apogee at the orbit's most *northern location. This was the parameter* used in the CAL Polarsat Study (2), page 33 and the "Tundra Orbit" Paper (1). It has the tremendous advantage of producing a ground trace where satellite motion at apogee is minimal due to the satellite's tendency to "hang", and the satellite's only movement being close to that of the earth rotation rate. As stated by the CAL Polarsat Study (2) page 32, satellite motion for either the Apogee plus or minus 2 hours case, or the Apogee plus or minus 4 hours case, the satellite motion can easily be handled with a non-tracking earth station antenna at UHF frequencies. (Figures 7 and 8 show the ground traces). This, however, would not be true at higher frequencies (such as at SHF and EHF) if narrow beamwidths are employed.

For the purposes of this paper an orbit with an apogee placed further south in latitude (58 degrees N) was selected. This corresponds to an argument of perigee of 288.4 degrees. The reason for the selection of this orbital parameter was to increase the east-west coverage across Canada. The shape of the resulting orbit is simiilar to that of the Soviet Molniya.

APSIDAL ROTATION RATE

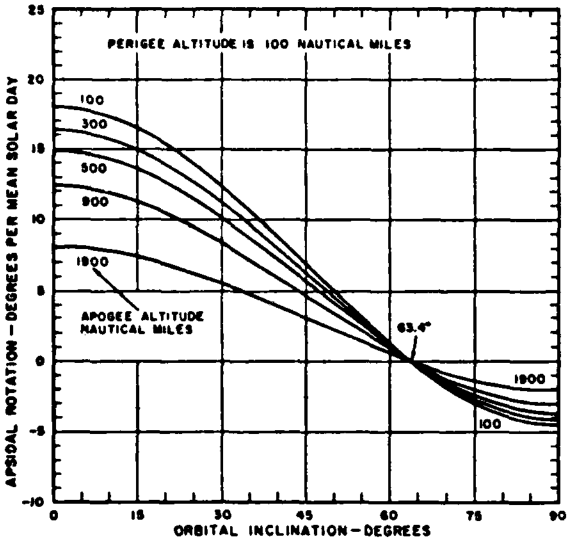


FIGURE 1. Reference (6).

VELOCITY CORRECTION
for
APSIDAL ROTATION

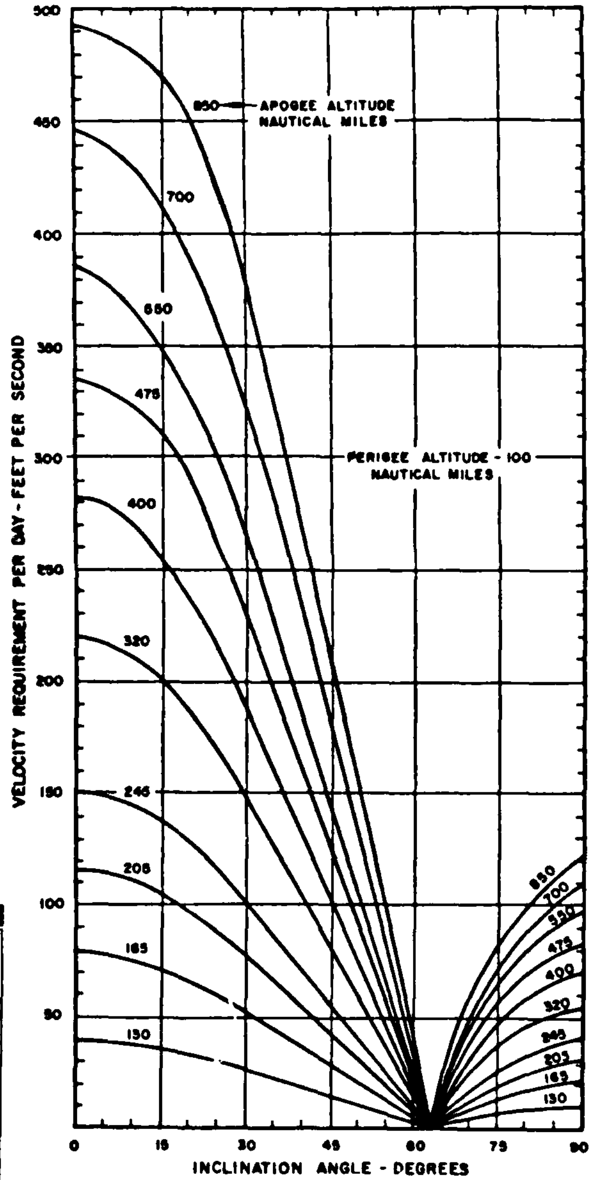


FIGURE 2. Reference (6).

TUNDRA Ground Trace

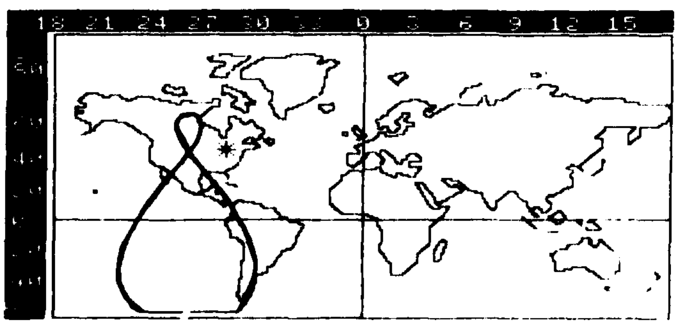


FIGURE 3. Reference (1).

NODAL REGRESSION RATE
Per day

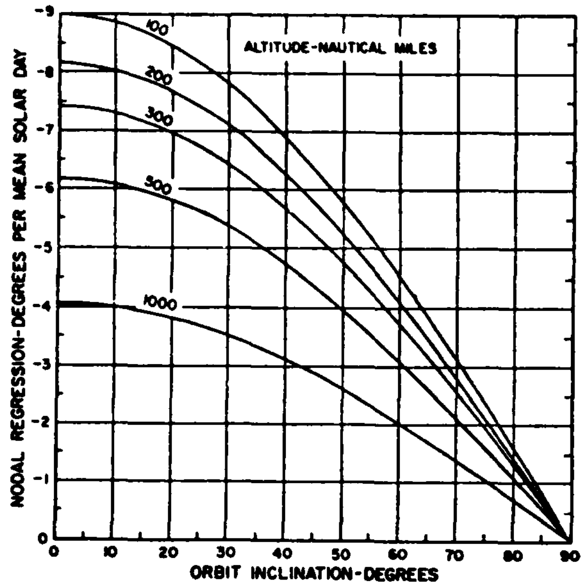


FIGURE 4. Reference (6).

VELOCITY CORRECTION
for
NODAL REGRESSION

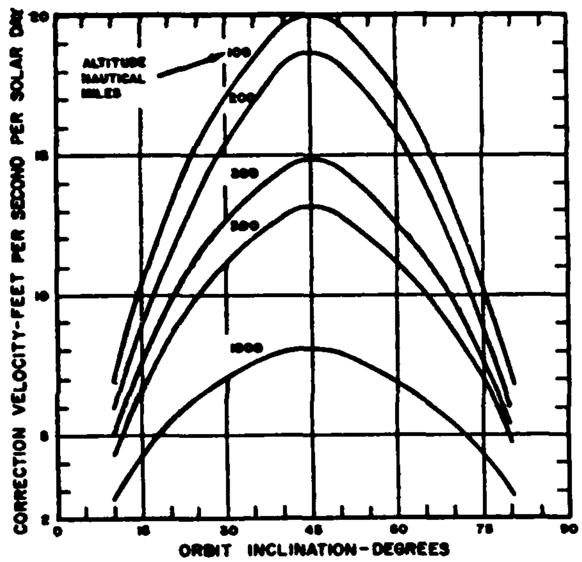


FIGURE 6. Reference (6).

NODAL REGRESSION RATE
Per Revolution

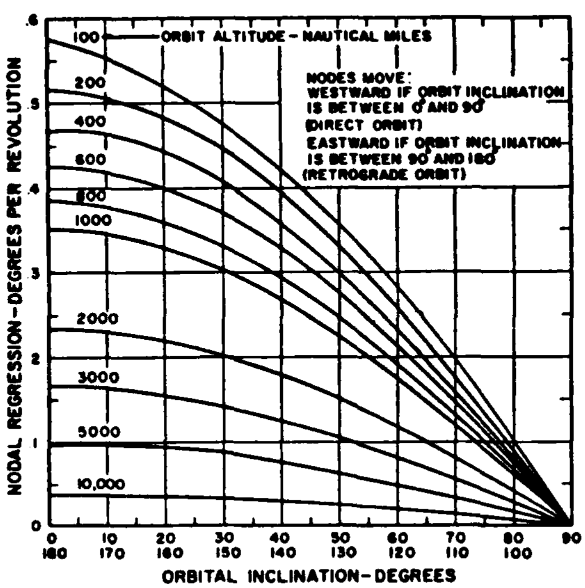


FIGURE 5. Reference (6).

Right Ascension ( ).

This parameter will place the ascending (and descending) node of the orbit at a given longitude. Consequently, the longitude placement of the ground trace is affected by this parameter. The excellent northern coverage of the Molniya makes the precise value of this parameter not too critical (in terms of user terminal coverage) for the northern hemisphere. Factors that would need to be considered would be orbital placement to reduce the susceptibility of jamming or interception of Canadian satellite communications uplink and downlink traffic.

For the purposes of this paper, a right ascension( ) was chosen to optimize the control of the satellite in the orbit from a single Ground Control Station located in North Bay, Ont. (See figure 9 and table 1). The azimuth/elevation graticule in figure 10 provides a good indication of where North Bay would place the satellite in the sky. The selection of a right ascension that is significantly different than this would necessitate another Ground Control Station in addition to the one proposed (by this paper) at North Bay. The alternative of a dependency upon crosslinking between satellites for satellite control is not a very fault tolerant, or survivable alternative with only one Ground Control Station. Conversely, if another Ground Control Station is utilized due to standard daily operating necessity, increased survivability would be achieved by the increased redundancy that an extra Ground Control Station provides.

A different right ascension could be chosen, in order to place one of the apogees over the center of Canada, with the other over Siberia (Figure 11). One reason for this would be to maximize user terminal antenna elevation angles over Canada. The azimuth/elevation graticule in Figure 12 provides an indication of the high elevation angles obtainable by such a right ascension selection. In strict terms of coverage, however, it is quite difficult to obtain the maximum redundant Canadian coverage, with the usage of this specific Molniya type orbit for communications between two points within Canada or within a thousand miles or so of Canada's coasts. With a 4 satellite network, each satellite will be used for a maximum 7 hours per day for a total available usage (and coverage for points within 1000 miles of Canada's coasts) of 28 hours per day for all 4 satellites. If, however, the apogees are placed on opposite sides of Canada (as chosen by this paper and illustrated in Figure 9), then each satellite can be used 14 hours out of each day. This results in 56 hours of total available usage (and coverage) for each day and gives redundant coverage equivalent to two satellites in continuous use for nearly all of Canada. (Only extreme eastern and western Canadian sites do not see opposite passes for the full 24 hour day). It also provides for a complete northern hemisphere capability and does not require cross linking.

COVERAGE

General.

As stated earlier, one of the prime reasons for examining a Molniya orbit is for its coverage of the northern latitudes. The satellite orbit selected in the Tundra paper (1) assumes satellite to satellite relay, or ground station relay of a three satellite constellation.

The constellation examined by this paper is a four satellite Molniya constellation (see figure 9). Analysis has shown that for a 24 hour day, from anywhere in the northern hemisphere, one of the four satellites will always be in view. This provides a comparable coverage of the northern hemisphere without the requirement to rely upon satellite to satellite crosslinking. The operational concept is to have the four satellites tracing an identical ground trace, with the sub orbital point of each satellite following the sub orbital trace of the previous satellite by six hours. Thus the satellites would be in four different planes, separated by 90 degrees in right ascension. Each satellite would be used for six hours (3 hours plus or minus from apogee) in each 12 hour orbit (i.e., used for two six hour periods daily). Although, the number of operational satellites in a Molniya constellation can likely be reduced to two or three satellites, the survivability, coverage and ground station tracking implications involved in this reduced number of satellites were outside the scope of this papers analysis.

An analysis of satellite look angles (for the four satellite constellation) from various locations around the world raised the following points:

a. complete 24 hours per day coverage of the northern hemisphere is provided;

b. no satellite tracking is required for the beamwidths likely to be utilized at UHF frequencies when all satellites are fully operational, (tracking is required for SHF and EHF if a narrow beamwidth is selected);

MOLNIYA GROUND TRACE
(TUNDRA PAPER)

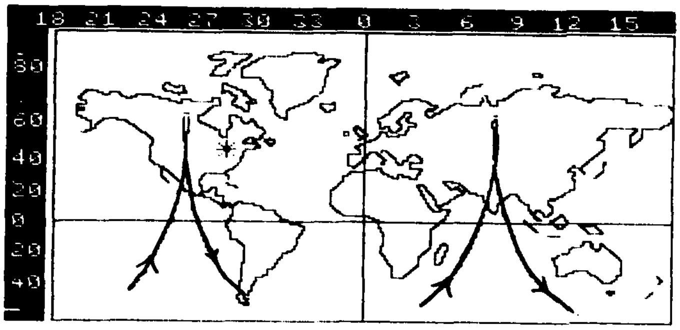


FIGURE 7. Reference (1).

MOLNIYA GROUND TRACE
- POLARSAT -
CANADIAN ASTRONAUTICS LIMITED

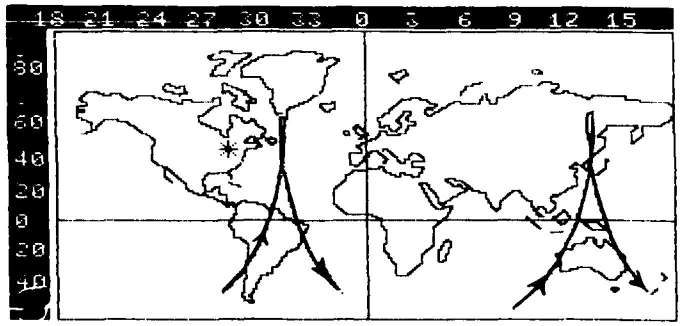


FIGURE 8. Reference (2).

CANADIAN MOLNIYA
(Right Ascension Centered on North Bay, Ont.)

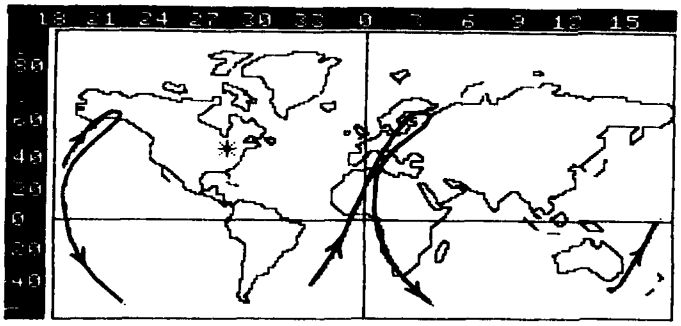


FIGURE 9.

CANADIAN MOLNIYA
(Optimized for Elevation Angles over Canada)

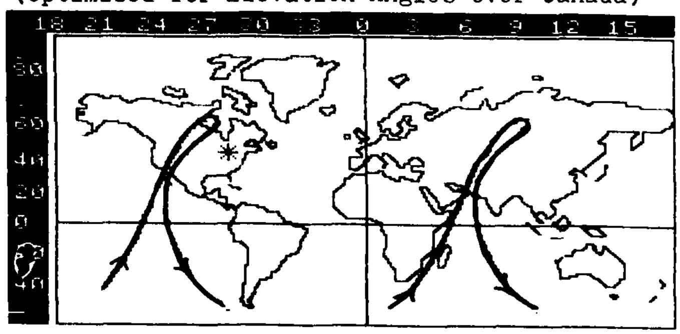


FIGURE 11

SINGLE SATELLITE POSITION OBSERVED

from

NORTH BAY, ONTARIO (46.33 N, 280.503E)

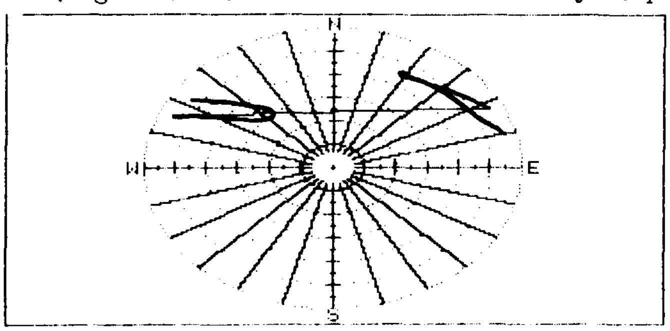
(CANADIAN MOLNIYA - Right Ascension Centered on North Bay)

TIME	AZIMUTH ANGLE	ELEVATION ANGLE	SLANT RANGE (km)
0410	059.1	7.3	16,531 North Bay Acquires
0420	053.3	11.3	18,422
0520	034.9	20.6	28,261 Apogee minus 4 hours
0620	028.5	22.0 (max.)	35,325 Apogee minus 3 hours
0710	027.0 (min)	21.6	39,421
0720	027.1	21.4	40,065 Apogee minus 2 hours
0820	028.7	20.3	42,792 Apogee minus 1 hour
0920	032.6	19.2	43,653 APOGEE
1020	038.3	18.2	42,688 Apogee plus 1 hour
1120	045.7	17.1	39,487 Apogee plus 2 hours
1220	055.1	14.9	34,992 Apogee plus 3 hours
1320	067.4	8.8	27,908 Apogee plus 4 hours
1335	071.2	5.7	25,774 North Bay Loses
1605	298.9	6.1	15,993 North Bay Acquires
1620	303.8	17.1	18,333
1720	315.5	37.1	27,133 Apogee minus 4 hours
1820	319.5	44.3	33,657 Apogee minus 3 hours
1835	319.7 (max)	45.3	34,941
1920	318.8	47.1	38,042 Apogee minus 2 hours
2020	315.3	47.2 (max.)	40,573 Apogee minus 1 hour
2120	310.5	44.8	41,420 APOGEE
2220	305.8	40.0	40,645 Apogee plus 1 hour
2320	301.6	32.9	38,204 Apogee plus 2 hours
0020	297.4	23.1	33,937 Apogee plus 3 hours
0120	291.4	9.1	27,525 Apogee plus 4 hours
0130	289.9	6.0	26,215 North Bay Loses

TABLE 1

CANADIAN MOLNIYA - LOOK ANGLES FROM NORTH BAY

(Right Ascension centered on North Bay as per Table 1)



AZIMUTH
(15° increments)
v.s.
ELEVATION ANGLE
(15° increments)

FIGURE 10

c. if one satellite fails, then 24 hour per day coverage is still provided for about 95% of the northern hemisphere, with about a 22 hour per day coverage for the remaining 5%. During this failure, only for a limited portion of the day, some tracking would be required for UHF. In addition, it would be necessary to switch the user terminal ground antenna over to a different portion of the satellite orbit (twice during each 24 hour period); and

d. after a single satellite failure, it is possible to realign the satellite constellation in right ascension (after a week or so of controlled satellite drift) to re-permit 24 hour per day coverage of the northern hemisphere with minimal tracking at UHF frequencies. The decision for this manoeuvre would be based upon remaining station keeping fuel, and the time required to replace the failed satellite with a new replacement satellite.

Of interest is the lack of perfect symmetry of the east/west Molniya northern loops when viewed from a ground user terminal. This lack of symmetry is evident in figure 10. In addition, due to earth curvature, the user terminal antenna at southern Canadian latitudes is normally pointing North East (NE) or North West (NW) at a higher elevation angle than was expected (a 20 to 85 degree elevation angle was obtained).

The high elevation angle is of considerable value when considering the power required to combat atmospheric losses at EHF frequencies. Figure 13 provides various curves demonstrating the increased amount of noise at lower elevation angles, and figure 14 provides various curves demonstrating the increased attenuation of signal due to lower antenna elevation angles. Figure 12 demonstrates the very high elevation angles obtainable with a Molniya orbit from a North Bay, Ontario site. Thus it is readily apparent, in contrast to geostationary satellites, a Molniya constellation, with its higher antenna elevation angles, will have considerably lower losses for high latitudes when utilizing the EHF band.

USER TERMINAL CONSIDERATIONS

Tracking.

As was discussed under coverage considerations, it is not considered necessary to track at the beamwidths likely to be utilized at UHF frequencies when the satellite constellation is 100% operational. However certain aspects of the tracking requirements (or lack there of) need be looked at:

a. A mobile tactical terminal, such as that used on a ship or aircraft, must track any satellite, whether it be geostationary or in a non-geostationary orbit. This is by virtue of the fact that the platform (ship or aircraft) on which the user terminal is located, is in constant motion. The tracking of a non-geostationary satellite would require in the user terminal only a simple feedback loop from a microprocessor that updates the satellite position. Orbital calculations, without perturbations, are relatively simple and quite adequate for tracking purposes. (For example, a program for a TI-59 hand calculator for this very type of calculation, which also has perturbations included, has been done (5). It is likely the satellite would have a beacon onboard (especially for SHF and EHF) and once the user terminal acquires the beacon, it would follow the satellite;

b. Since the danger of losing a satellite is always present, it would be necessary to ensure that the user terminals could still utilize the remaining satellites in the constellation for the maximum time (in the event of a single satellite failure). This, as discussed under coverage considerations, would mean that tracking is required in the user terminals (even for UHF). In addition, tracking antennas are always required if low power large bandwidth signals are being handled (otherwise ground interference can become intolerable). This tracking requirement would have little impact on terminals on ships and aircraft (as they have to track anyway), but it would have a major impact upon fixed ground terminals which normally do not track for utilization of geostationary satellites. A cost analysis needs to be done upon the impact of placing a tracking requirement on these terminals to evaluate the added cost to obtain complete northern hemispheric coverage as compared to about 70 degrees north and south coverage for a multiple geostationary satellite constellation; and

c. It is possible that more than one antenna may be desireable at SHF and EHF frequencies in order to minimize the interuptive effect of switching (and possibly shifting antennas) from one satellite to another. However, the concern of switching is a relatively

CANADIAN MOLNIYA - LOOK ANGLES FROM NORTH BAY
(Optimized for High Elevation Angles over Canada - see Fig.11)

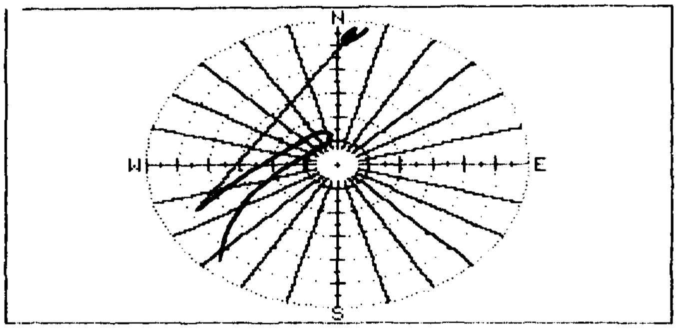


FIGURE 12

AZIMUTH
(15° increments)
v.s.
ELEVATION ANGLES
(15° increments)

Attenuation of signal with frequency.

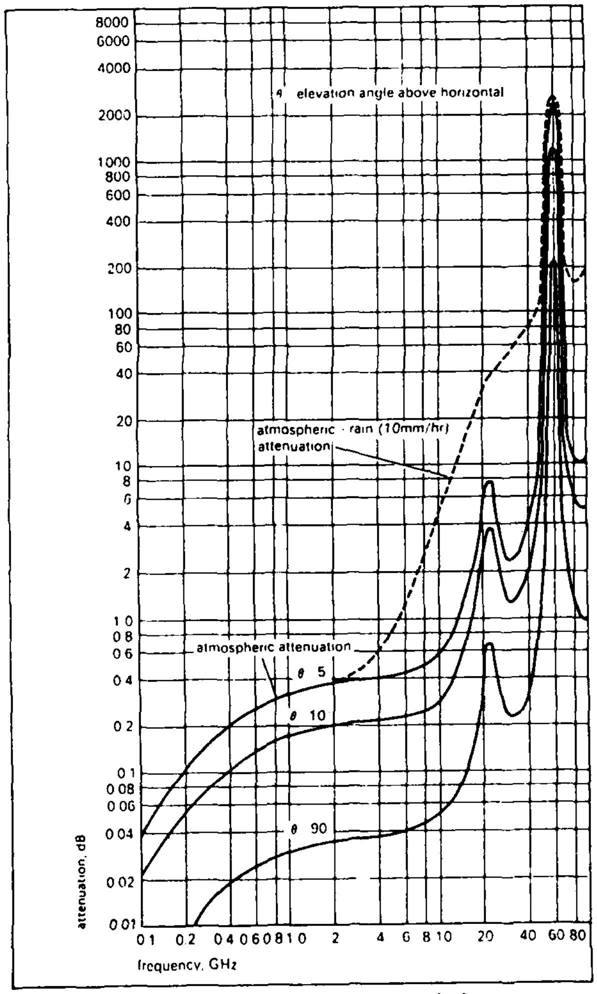


FIGURE 14. Reference (8).

Variation of noise with frequency

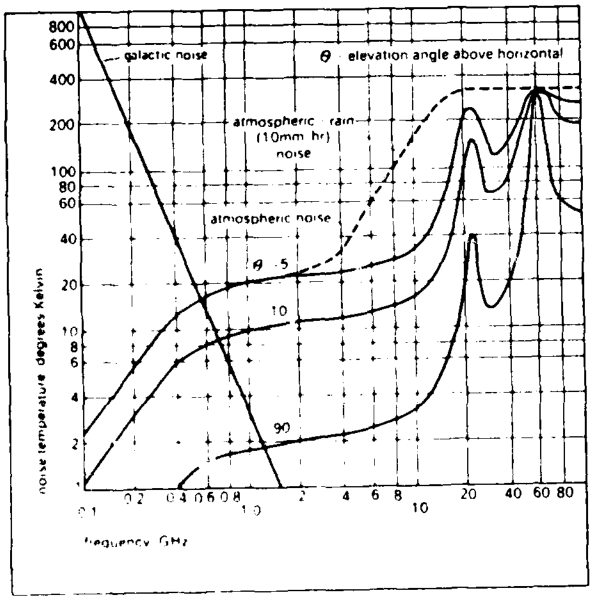


FIGURE 13. Reference (8).

minor one, as many communications satellites are periodically interrupted or operated on a schedule basis. In fact, for very high latitudes, the need for two antenna may be more applicable to user terminals that utilize Geostationary Satellites. For example, because of the high latitude, 80 degrees North, the antenna elevation angle towards a Telesat Canada Anik satellite from Eureka, North West Territories, is only 1 degree, which is substantially below the normally accepted lower limit of 5 degrees. To reduce the large increase in atmospheric fading of low elevation angles (particularly during the summer), compared with locations (or satellites) that permit high elevation angles, site diversity earth stations are used at Eureka (7).

DOPPLER

An analysis needs to be done to determine whether the slight doppler shift associated with a Molniya orbit will have an impact upon the design of the spacecraft, or the user terminal. (A relative satellite movement of 10,000 km, spread out over three hours, is about the maximum movement for a four satellite constellation). The user terminals that would experience the most doppler shift are those whose location is roughly equivalent, in longitude, to the northerly excursions of the satellite. (i.e. a *longitude roughly equivalent* to the longitude of the sub-orbital point of the satellite when at apogee).

When one satellite fails, (and it is necessary to shift the direction of the user terminal antenna to the satellites travelling on the other side of the northern hemisphere) the doppler shift of this "back up" portion of the orbit is minimal. However, for any time portion of the satellite orbit greater than apogee plus or minus three hours, there would be an increased doppler as the satellite is closer to the earth and the satellite is moving at a *higher velocity*.

For most communications applications the doppler shift is small and should not present major problems. If it is required to retain synchronization with special signals, a doppler error correction capability may be applied to each user terminal. It would, however, complicate user terminal design and cost. If the doppler error correction varies for various different user terminal locations, then a limited amount of orbital predictions would be needed at the user terminal to retain synchronization. It may be more economical to place the doppler error correction onboard the satellite. This would necessitate onboard processing (OBP) on the satellite. A limited amount of data exchange (handshaking) would then need to be done between the satellite and the user terminal (in order that the user teminal can pass its unique geographical position to the satellite) and thus have its unique *doppler error correction* applied by the satellite. The satellite could also update the user terminal ephemeris data each time this data exchange takes place. This way the user terminal always has an up to date ephemeris element set in case the beacon is lost and the satellite has to be reacquired. If the satellite does not have onboard celestial navigation it can have its own master ephemeris data updated by the satellite control station. This technique is commonly employed by Navigation Satellites.

SPACE CRAFT CONSIDERATIONS

Batteries.

A single space craft in a Molniya type orbit requires considerably less space and weight allocated to batteries (than that of the standard geostationary spacecraft) because it is not normally eclipsed during its operation periods. The worst case eclipse condition for a single satellite will occur near winter solstice, when the sun is in the southern hemisphere and casting an earth shadow north of the equator. For the 12 hour orbit, under the worst case conditions, the satellite will be free of eclipsing for 4 hours and 32 minutes after apogee, which allows adequate protection, even for longer coverage passes. There is also, as with geostationary orbits, the possibility of long duration lunar eclipses. These events are rare however, and with either three or four satellites operating the lunar eclipses can be avoided. (As will be discussed in a subsequent paragraph, there is no requirement to operate the spacecraft during an eclipse with a four satellite constellation).

The case examined in this paper utilizes the satellite 3 hours either side of apogee. This clearly presents no eclipsing problem. If one satellite fails, it may be necessary to operate a satellite at times in excess of apogee plus or minus 4 hours, 32 minutes (where eclipsing could occur during winter solstice). Only if one satellite fails, during the worst case of winter solstice, is there a possibility that minimal satellite eclipse operation may be necessary. This eclipse operation is best avoided by passing out time schedules of operation and satellite assignment different than that for normal

operations. The minimal eclipse operation could also be avoided by shifting the orbit (right ascension) of just one of the satellites so that their planes are spaced by 90 degrees, 135 degrees, and 135 degrees (or 6 hours, 9 hours, and 9 hours between satellites) instead of the standard 90 degrees, 90 degrees, 90 degrees and 90 degrees (i.e. 6 hours between satellites). Two satellites could also have their orbit shifted (as was suggested earlier) so that the satellite constellation is optimized for only three satellites, with these satellites evenly spaced (with 120 degrees between orbital planes - or 8 hours between satellites). However these orbital shifts require days to implement, and necessitate different tracking orbital parameters for the user terminals. Even with only a two satellite constellation, if the satellites are phased correctly (90 degrees apart in right ascension), eclipsing should not be a problem.

The main reason for the batteries for three or four satellite constellations would be for the limited satellite housekeeping and operation during the initial satellite deployment (before the solar cells can be deployed to provide power). Assuming that the spacecraft is shut down during its eclipse and close-to-the earth southern hemisphere perigee orbital path portion, battery power may be required only for autonomous (housekeeping) operation of the spacecraft. It will likely be necessary to provide power to a limited number of critical housekeeping functions during the eclipsed portion of the southern pass (in particular the command receiver). However it should be noted there is no requirement to utilize the spacecraft as a satellite communications relay during this portion of its orbit. As batteries consist of about 10% of the spacecraft dry weight, a reduction of 50% (arbitrarily chosen for illustrative purposes) in the required batteries, would reduce the spacecraft dry weight by about 5%. This would bring about a reduction in this aspect of spacecraft cost.

Radiation Protection

A Molniya type orbit will pass through the Van Allen belt twice every twelve hours. Inclined elliptical orbits (such as the Molniya), pass through varying regions of radiation intensity, and detailed analysis must be performed on each specific orbital case. "In general, however, inclined orbits intercept less of the intense radiation field, and highly elliptic orbits can be designed to spend a comparatively short period of time in the regions of intense radiation..." (2).

The solar arrays are likely to be the satellite component most affected by Van Allen belt radiation. It is not certain if the type of stabilization of the spacecraft (and consequently the position of the solar arrays) is of major importance when repeatedly encountering the Van Allen belt.

While a three axis spacecraft is in general capable of generating more solar power than a spin stabilized spacecraft, it is not clear if the orientation of the solar arrays of a three axis spacecraft may make it more vulnerable to radiation degradation than a spinner. The consideration here is that the spinning movement of the spin stabilized spacecraft arrays would distribute the radiation damage received during spacecraft transition through the magnetosphere. A counter to this statement is that a larger solar array could be used on the three axis spacecraft to compensate, and thus increase the power available at end-of-life. Another concept is that since the spacecraft is eclipsed during the southern hemisphere pass (and transition through the magnetosphere), the solar arrays of a three axis spacecraft could be temporarily reorientated for the magnetosphere pass to minimize radiation degradation. However this re-orientation concept may be too complex and costly to make its utilization worthwhile. In addition, if a military spacecraft is properly hardened, it is likely that the radiation from the Van Allen belt need not be of major concern (and thus the choice of stabilization method not affected by radiation considerations).

If military radiation hardening is applied to the satellite, the effect of the magnetosphere upon the satellite is minimized and it is quite possible that satellite life comparable to that of geostationary satellites can be obtained. Of course the entire concern with respect to solar array degradation could be eliminated through the use of a nuclear power supply.

Apogee Kick Motor and Launch Requirements

The apogee kick motor is normally utilized to perform the combined inclination change and circular orbit injection manoeuvre. For a Molniya type orbit the energy required here is considerably less than that for a geostationary orbit. As a rule of thumb the energy required to place a satellite in a Molniya type orbit is approximately equivalent to that required to place a satellite in a Hohmann transfer orbit for a geostationary orbital slot. In general, from a high latitude launch site, such as

Churchill, Manitoba, (or, on the eastern seaboard, East Quoddy), launchers with 1/3 the boost capability can be used to launch Molniya satellites as compared that for geostationary satellites. In addition the inclination change required to be performed by the apogee kick motor would depend upon the launch latitude and azimuth (the launch site safety arcs), and the inclination imparted by the launch booster. This energy can be minimized by careful launch window selection.

In general, this paper's 12 hour inclined elliptic orbit could be achieved by a spacecraft with a considerably less powerful apogee kick motor than that required by the standard geostationary satellite. Dependent upon the payload weight, much of the energy requirement could be performed by the booster, minimizing the size of the apogee kick motor. As the apogee kick motor takes up approximately 50% of the satellite's mass, this would mean a substantial weight and cost saving. A restartable motor is, however, still required for orbit stabilization and periodic orbit correction. A trade-off study on the apogee kick motor requirement would need further examine if most of the orbital stabilization and correction could be done by the spacecraft's attitude control system (ACS) thrusters.

Survivability

A spacecraft constellation in an inclined elliptical orbit is a very survivable constellation. Since each satellite is in a separate orbital plane, a separate antisatellite (ASAT) device would be required to attack each Molniya satellite. In addition current ASAT technology would permit the attack of the satellite only during its relatively low (southern hemisphere) altitude pass. The Molniya satellite perigee altitude can be easily and substantially altered by a very slight energy expenditure at apogee. This capability (to vary perigee parameters) is an effective ASAT counter-measure if there is an advance warning of an impending attack and would greatly complicate the tracking and targetting necessary for a successful ASAT negation.

Conceptually, upon receiving warning, the satellite's orbit could be altered by an energy thrust at apogee sufficient to cause the ASAT attack to be unsuccessful. As the largest change in this defensive orbit shift takes place at perigee, it would not significantly degrade the satellite's communications capability. The orbit could be easily re-adjusted, after attack, to its previous position. The warning received could be from external intelligence sources, or even from autonomous sensors onboard the Canadian Molniya satellite. The degree of response to a threat could be controlled from the Ground Control Station, or preprogrammed as part of the autonomous satellite operation package.

Survivability could be enhanced by multiple Control Stations (although as discussed, only one at North Bay is necessary to achieve the required coverage). Crosslinking between satellites (in addition to multiple Control Stations), would also enhance survivability, as the loss of one Control Station (and its coverage area) would not affect the satellite constellation operation. Redundant control would be provided by one of the multiple Control Stations, and the spacecraft crosslinking would ensure the appropriate coverage is obtained.

Autonomous operation is required for the inclined elliptic spacecraft to ensure the basic minimum of housekeeping functions are performed during the southern hemispheric pass. The autonomous requirement could also impact upon the selection of the stabilization method (three axis compared to spin stabilized). It is noted that autonomous operation is a military requirement in any case, regardless of the orbit selected, to obviate outages caused by failure of the satellite Ground Control Station.

CANADIAN LAUNCH

One aspect that need be considered is that the selection of a Molniya orbit retains the option for a Canadian launch sometime in the future. A geostationary satellite would be very energy expensive to launch (from Canada) due to the large inclination change required. A Molniya satellite with a 63.4 degree inclination launched from Churchill, Manitoba (58 degrees, 44 minutes North) would have only a 5 degree inclination change required (for an easterly launch). This small required inclination change, coupled with the lighter weight requirements of the Molniya (less batteries, and a very small, or no, apogee kick motor) makes a Canadian launch a technically feasible and possibly attractive option. Bristol Aerospace has done a preliminary study into the cost feasibility of a Canadian Launch Vehicle (4).

If a Molniya satellite were launched from Churchill, it could conceivably be placed directly into the required orbital ellipse (with a perigee of 616 Km and an apogee of 39,770 Km) at an inclination of about 59 degrees. The line of apsides

would be permitted to rotate until the apogee is in the correct orbital position. At this time the small apogee kick motor (or the ACS thrusters) would be fired to make the slight 5 degree inclination change and minimize the apsidal rotation (A characteristic of 63.4 degree inclinations). When the required nodal rotation has taken place to permit the correct right ascension to be achieved a final firing of stationkeeping thrusters would minimize the nodal rotation and fix the satellite in its correct orbit. In addition, dependent upon the Canadian launch window, and other factors, various other sequences could be followed to place the satellite in orbit. A similar launch to orbit concept could be followed by a launch from East Quoddy.

Dependent upon the size of the required inclination change, and the energy and guidance precision in the launch booster, it is possible that an apogee kick motor is not required at all (for a Canadian launch). The requirement for the apogee kick motor would need to be examined further in terms of survivability requirements (excess energy for ASAT avoidance manoeuvres), launch site latitude, launch site safety arcs, launch booster capability, and required station keeping fuel for maximum satellite life.

Economic, political, and military security matters need be examined in detail when considering a Canadian launch. The technical expertise of various Canadian firms (such as, for example, Bristol Aerospace (small apogee kick motors and boosters) and Litton (guidance computers)) could be greatly enhanced by such a project.

CONCLUSION

CF satellite communications requirements could be satisfied by an inclined elliptic two satellite constellation in an orbit similar to the Soviet Molniya satellites. Worldwide northern hemispheric coverage (including all of the northern polar region), coupled with completely redundant Canadian coverage (in the event of a single satellite failure) can be obtained by a three or a four satellite orbit constellation selection. Initial indications are that the cost impact on user terminals will not be significantly greater (for inclined elliptic orbits) than those designed for geostationary satellite use, and the costs for the satellite and the launch booster are likely to be substantially less than those for a geostationary satellite. In addition the selection of a Molniya type orbit provides the required operational polar coverage and increased elevation angles (for northern utilization of EHF/SHF) impossible to attain with a geostationary deployment.

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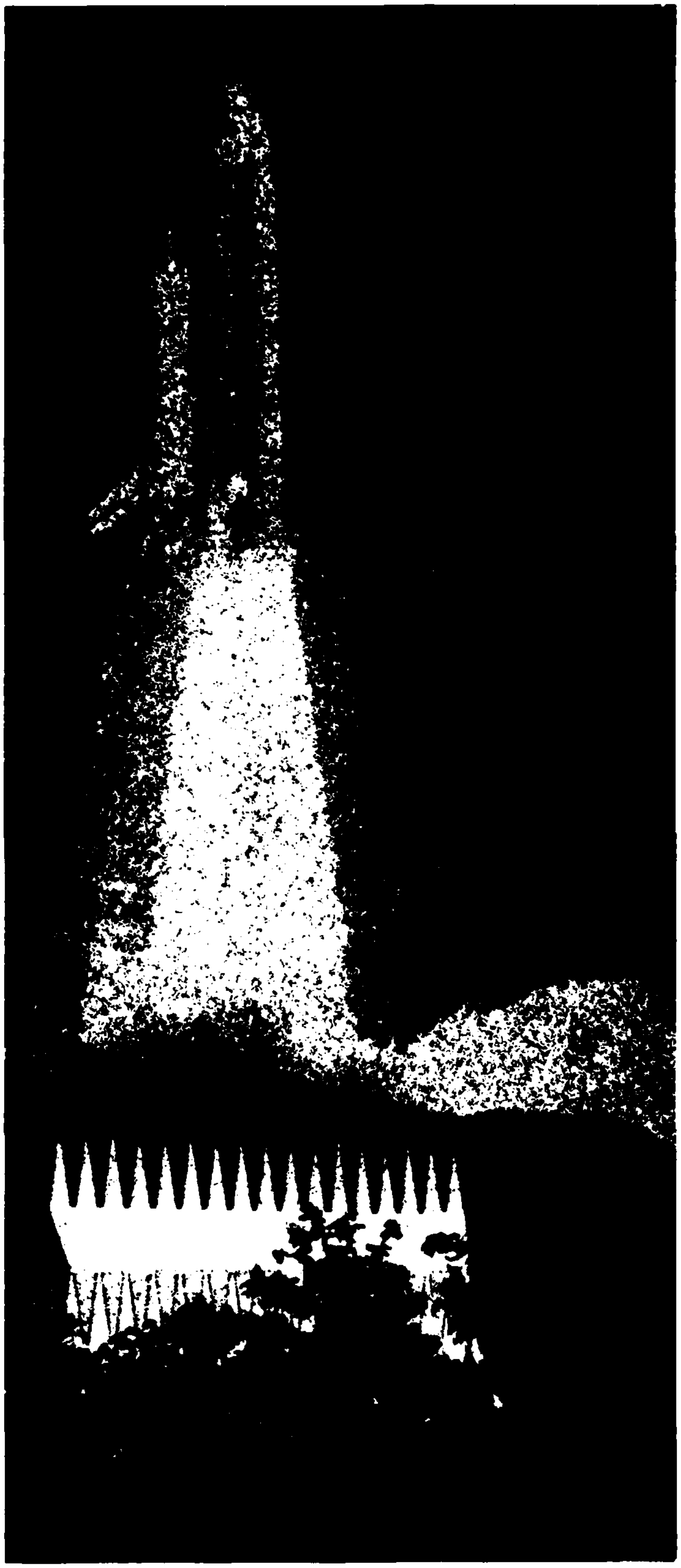

Session 2

Network Control/Architecture

Session Chairman: Col. J. Monroe, *USAFA*

The Papers

Invited Paper—Military SATCOM Architecture

Invited Paper—An Operations Language for Military Space Ground Systems

A Console Display Architecture for Military C³ Ground Systems

AD P002146

AN OPERATIONS LANGUAGE FOR MILITARY SPACE GROUND SYSTEMS

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ABSTRACT

The trend in military space ground system architecture is toward larger amounts of software and more widely distributed processors. At the same time, life cycle cost considerations dictate that fewer personnel with minimized skill levels and knowledge operate and support these systems. This "squeeze" necessitates more human engineering and operational planning into the design of these systems. Several techniques have been developed to satisfy these requirements. An operations language is one of these techniques. It involves a specially defined syntax for control of the system. Individual directives are able to be grouped into operations language procedures. These procedures can be prepared off-line ahead of time by more skilled personnel and then used to ensure repeatability of operational sequences and reduce operator errors. The use of an operations language also provides benefits for the handling of contingency operations as well as in the system testing and validation programs.

I. BACKGROUND

The concept of an operations language has evolved over the past years due to several factors. First and foremost, it was recognized that the operation of spacecraft ground systems involved performing sequences of activities that were either 1) repeated frequently; such as housekeeping during every spacecraft pass, routine communications switching; or 2) were not exercised often, but when required had little room for error; such as spacecraft contingency operations. Second, a need to standardize input techniques developed, since different subsystem elements often employed different techniques of manual input implementation.

These reasons drove system developers to a standardized syntax for affecting manual control over a system. The resulting syntax inputs were then used by the operations personnel during planning and subsequent real-time operations. It was realized that the ability to group and pre-order these syntax inputs provided a real benefit in terms of being able to exercise "canned" sequences of operations for both normal and contingency conditions.

This concept is not unique to any specific system; some of these ideas have surfaced independently in various spacecraft ground systems. While not unique, the establishment of an operations language as a systems engineering entity has been given special treatment by OAO Corporation over the past years, starting in the civilian space program and migrating to the military space arena.

The evolution of an operations language is illustrated in figure 1. At NASA's Goddard Space Flight Center, the use of procedures originated with the following spacecraft missions: Applications Technology Satellite-F (ATS-F), Orbiting Solar Observatory (OSO), Atmospheric Explorer (AE), the TIROS-N weather satellite, and the International Ultraviolet Explorer (IUE). These missions used primative forms of operations languages with acronyms such as ASP, ATLAS, PCL and CCL. From the various experiences with these ground system operations languages, a study was initiated to combine these approaches into a single standardized language. This study resulted in development of the System Test and Operations Language (STOL). STOL gleaned the best features from the predecessor languages and discarded the hinderances. STOL has now become the Goddard Space Flight Center (GSFC) standard for both control centers and spacecraft integration and test operations for the 1980's. Missions using STOL are the Solar Maximum Mission (SMM), LANDSAT-D, SPACELAB, Space Telescope, the Multi-Satellite Operations Control Center, and all Modular Mission Spacecraft (MMS) derivatives. OAO Corporation participated in the development of STOL and provided the first STOL implementation for the SMM Integration and Test system at GSFC. Subsequently, OAO has implemented STOL for other NASA missions and has taught STOL operations and implementation to industry. This concept of an operations language has been transfered to the military space ground system environment via the Global Positioning System (GPS) mission and has migrated to the Air Force's Data Systems Modernization (DSM) program and has potential application to future systems such as the Shuttle Operations and Planning Complex (SOPC).

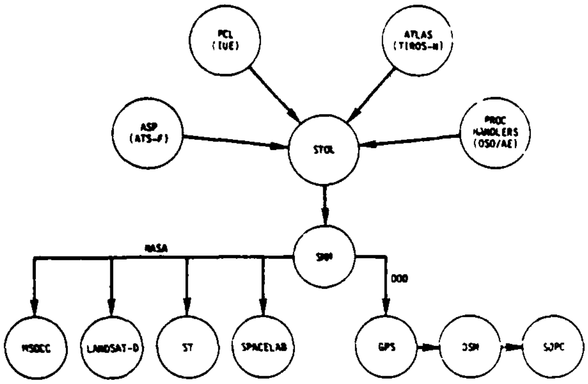


Figure 1. Evolution of the STOL Operations Language

II. OPERATIONS LANGUAGE IN THE MILITARY SPACE ENVIRONMENT

The trend in military space ground systems is in the direction of increased data processing sophistication. This sophistication is evidenced by larger amounts of software (as measured by source lines of code) and increasingly distributed processors in the ground systems. These data processing resources (software and hardware) bring with them more demanding requirements for performance monitoring and system configuration control. Likewise, the space vehicles and payloads which are supported by these ground systems demand control and monitoring of an increasing number of complex subsystems and on-board computers. Due to the costs of these space vehicles, the tolerance for critical errors and timely responses to contingencies is still a key factor in the operation of any ground system.

The operational exigencies of these systems have not abated, however there has been constant pressure during system acquistions to reduce the attendant life cycle costs of these systems. A major life cycle cost element, and one of the most visible, is the composition of the operations and maintenance personnel organization required for a ground system. Specifically, much attention has been focused on the number of personnel required to operate a space ground system and their necessary skill and training levels. The trade-offs involved in minimizing these parameters often justify additional acquisition funds to be used to implement automated techniques which can further reduce manpower-related life cycle costs. These techniques focus on aiding the man-in-the-loop decision making processes and the display and control man/machine interface.

Man's role in space ground systems is evolving to one of being a resource to close unplanned open loops in the system operations, as illustrated in figure 2. Typically, software is developed to accept functional inputs, process them, and autonomously provide functional outputs. These inputs and outputs can relate to payload data, spacecraft telemetry and commands, or ground system status and controls. Further, automated scheduling functions are being developed to asynchronously start and stop such operations. Due to the inability or infeasibility to program all possible contingency situations and the risk associated with letting such automated activities be performed unattended, man continues to have a significant role in space ground systems. This role however, tends to be a monitor of the status of the execution of the system and requires him to be the primary decision maker when conditions are non- nominal. This generally occurs when portions of the monitored system status do not appear to be consistent with each other or when the system has been programmed to signify an alarm state.

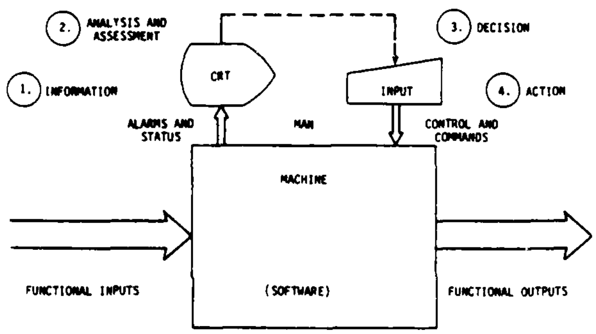


Figure 2. Man's Primary Role is to Close Loops

Situations such as these initiate a stimulus-response sequence whereby the system controller must analyze the displayed information to assess alternatives and reach some decision. Most decisions require the performance of some sequence of control or command activities to affect the desired results. These man-in-the-loop situations may either be nominal cases where it has been determined that man's positive control over a situation is desired or non-nominal cases. These non-nominal situations can range from the fairly routine, for example where a ground system equipment reconfiguration is needed; to a time-critical spacecraft emergency. These situations, especially the later, are characterized by the need for quick responses, often requiring lengthy response sequences, and affording little tolerance for errors. To compound this problem, exercising and training of non-nominal situation responses is generally limited.

To summarize the problem of controller responses in a military space ground system; the demand for speed and accuracy of command and control response sequences often demands utilizing the skills of the available controllers (which system acquisition pressures force us to reduce) to exercise control over data processing and spacecraft systems which are becoming increasingly complex.

System control implementation presents significant trade-offs to the designer. Controls can be simplified by increasing the amount of software involved on the computer side of the man/machine interface. For example, a complex sequence of activities could be coded into a software routine which is executed via a simple input sequence. The problem with this approach is that hard-coded responses tend to become inflexible and difficult to modify. System flexibility has become key criterion of system "goodness" since it is well recognized that over a system life cycle, equipment, communications, and software will (and should) evolve. A flexible system therefore is desired to be able to adapt to changing requirements. Flexibility decries hard-coded routines because of the attendant configuration management requirements, test considerations and the human resources required for implementing changes.

An alternative to high level hard-coded controls is manually initiated discrete response sequences (still via software) but at a very low level. These sequences provide flexibility in that options are easily selected and system adaptations are easily accommodated. The problem which results is that the required response sequences tend to become long - since they consist of, by definition, many simple discrete actions. Previous space ground systems have addressed the problems that this response approach brings to bear by the use of written procedures or checklists to guide the controller through the proper sequence of steps to accomplish an action. Although paper procedures are easier and less costly to manage and change than coded software, problems are still involved. These problems include the ability to quickly locate and use the desired procedure and the fact that manual transcription or data entry errors are common.

The operations language has emerged as a technique to bridge these extremes and yet has lost little in the compromise.

III. OPERATIONS LANGUAGE DIRECTIVES

The most basic element of an operations language is the operations language directive. A directive is the lowest level of control that can be exercised in a system. This level of control includes both control of software processes (such as, start telemetry limit checking, or present a specified display on a particular CRT) and the software control of hardware (turn on a remote tracking station's high power amplifier, resynchronize a crypto device, initialize a CPU, etc.). This level of control can be visualized by imagining a totally quiescent system and then identifying each lowest level discrete action over which system operations personnel need control.

The syntax of a directive in its most basic form is:

verb parameters

A directive consists of a verb and an optional set of parameters. Basic capabilities of an operations language include the use of a standard character set as well as the use of constants as parameters (including, as appropriate, decimal, binary, octal, hexidecimal, real numbers, and strings). The list below illustrates the use of various forms of parameters which each accomplish the same function in a system.

DIRECTIVE	PARAMETER	PARAMETER TYPE
CMD	0'ØØØØ557	OCTAL
CMD	7Ø4	REAL
CMD	XMTR1OFF	ALPHANUMERIC (MNENOMIC)

This example uses a directive (CMD) to transmit a command to a spacecraft. In the first form, the actual command uplink data the (bit stream) is given by an octal representation. The second implementation of this directive uses a real number, where 704 is an assigned command number to represent the command data. The third form uses a mnemonic string (transmitter #1 off) to represent the command in the system's data base.

Other uses of parameters include telemetry mnenomics and telemetry frame address specification, such as:

a) LIMITS OFF,BAT1VOLT
b) CHART TLM(4,12)

where a) is a directive to turn off limit checking for the battery #1 voltage measurement and b) is a directive to begin strip charting the value of telemetry main frame word 4, subcommutated word 12.

The original STOL concept defined a basic set of directives in three areas: command, telemetry, and input/output. These areas have been increased in recent implementations and now also include extensive ground system control.

IV. PROCEDURES

The major benefit of an operations language is provided by the capability of developing operations language procedures. The concept of operations language procedures centers on the ability to prepare off-line, sequences of directives which are grouped together and given a single

procedure name. Procedures are filed in the system on an immediate access storage medium where they can be retreived and executed via a single reference. This single reference is actually a directive, the START directive, with the name of the procedure as the argument. Procedures are valuable because they provide repeatible orders of fixed sequences. These procedures are able to be prepared off-line and fully tested and validated prior to their release for operational use. In routine operations, procedures are valuable since they can relieve system controllers from repetitive tasks - thereby reducing the possibility of operator errors.

There are several key features of an operations language/procedure implementation. Run-time visibility is important since a procedure is merely a technique for providing a short cut for fully manual control. The man-in-the-loop should always have visibility into the sequence of directives being executed. This is accomplished by an interpretive execution of each directive in the procedure. Manual controls must always be able to be exercised over the procedure execution. This includes the pre-emptive directive *HALT* which stops procedure execution immediately. Also, built-in controls can be provided by the procedure writers by the inclusion of procedure control directives such as HOLD (an indefinite wait until the controller enters the GO directive), or WAIT n (where n is some number of seconds). The ability for a controller to put the procedure execution into a single step mode (via the STEP directive) is also a key element of an operations language implementation.

It should be stressed that procedures are not intended to be substitutions for software. Allocations are made in every system design in terms of what is to be fully automated and what is to be made more discrete in terms of the desired level of control. Procedures are powerful because they provide the flexibility to permit more automation and standardization, but still with execution visibility and manual controls and overrides available. Procedures are provided with additional power when extended by the concepts of argument substitution, nesting and arithmetic and logical condition testing and branching. The basic directive format presented earlier when extended for use in a procedure, results in the modified format:

label verb parameters :comment

where the label field has been added for branching and the comment field has been added for self-documentation. A sample procedure is presented in figure 3. This entire procedure could be executed under the watchful eye of a system controller merely by the entry of the directive:

START SMPLPROC

```
PROC SMPLPROC
;
;     THIS IS A SAMPLE PROCEDURE
;
;     IT PRESENTS A DISPLAY OF A SPACE VEHICLE'S (SV's) STATUS
;     ON THE CONTROLLER'S CRT; WAITS FOR HIS INPUT TO
;     CONTINUE; TURNS ON A GROUND STATION's HIGH POWER
;     AMPLIFIER (HPA) FOR COMMANDING; CHECKS CONSTRAINTS TO
;     VERIFY THAT TELEMETRY INDICATES THAT THE SV's
;     REACTION WHEEL (RW) IS CURRENTLY OFF; TRANSMITS
;     THE COMMAND TO TURN THE RW ON; WAITS FOR
;     COMMAND/TELEMETRY PROPAGATION AND PROCESSING DELAYS;
;     PERFORMS A FUNCTIONAL VERIFICATION OF THE COMMAND VIA A
;     TELEMETRY CHECK; AND TURNS OFF THE HPA
;
        DISPLAY     SVSTATUS        ; DISPLAY SV STATUS ON CRT
        HOLD                        ; HOLD FOR OPERATOR RELEASE
        CONFIGURE   HPA=ON          ; TURN GROUND STATION HPA ON
        VERIFY      RW1STAT=OFF     ; CONFIRM RW IS NOW OFF
        CMD         RW1ON           ; SEND COMMAND TO TURN RW ON
        WAIT        10              ; WAIT 10 SECONDS FOR CMD/TLM
                                      DELAYS
        VERIFY      RW1STAT=ON      ; CONFIRM RW IS NOW ON
        CONFIGURE   HPA=OFF         ; TURN OFF THE HPA
        ENDPROC                     ; END OF PROCEDURE
```

Figure Sample Procedure

One operations language implementation principle developed with STOL is the principle of run-time traceability. Similar to run-time visibility, this principle dictates that every directive executed within a procedure should be able to be traced and identified, if necessary, due to system anomally investigations, etc. This dictates the requirements for a system log or equivalent to record each directive that was executed. Typically, this log is time-tagged.

V. APPLICATIONS OF OPERATIONS LANGUAGE PROCEDURES

Operations language procedures have application in many areas in a space ground system. Space vehicle contacts can be structured utilizing procedures extensively. These contacts can include routine housekeeping/state-of-health contacts, as well as regular, but less frequent types of contacts such as battery reconditioning, or orbit/attitude maneuvers. Non-nominal situations can often be dealt with by the use of preplanned contingency procedures. With adequate space vehicle simulation capabilities, many contingency procedures can be developed, tested and kept on file until (if) they are needed. Figure 4 illustrates a sequence of contingency activities for a space vehicle which could be implemented in operations language procedures.

Since the hardware, software and communications components of modern ground systems have grown more complex and more widely distributed, the number of actions and degree of knowledge required to reconfigure these systems has also increased. Activities required to reconfigure system components can be greatly simplified by the use of operations language procedures. Activities easily accomodated by procedures include, hardware reconfiguration, software/mode control, readiness testing and remote diagnostic execution. Again, both normal and contingency operations are accommodated easily by the use of procedures.

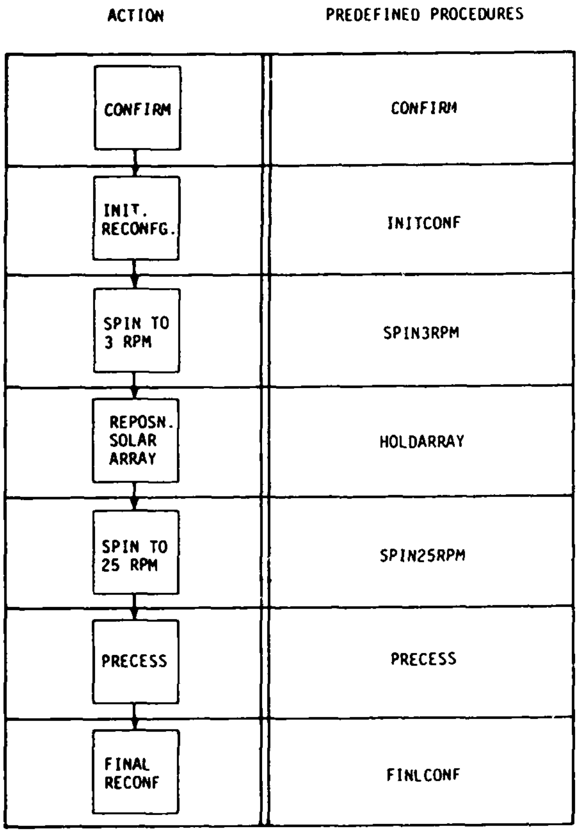


Figure 4. Space Vehicle Contingency Procedures

Procedures can also be used as the basic units of scheduling since modern systems often have requirements for schedule driven operations. As illustrated in figure 5, procedures can serve as building blocks to produce arbitrarily complex scheduled activities for both space vehicle and ground system support.

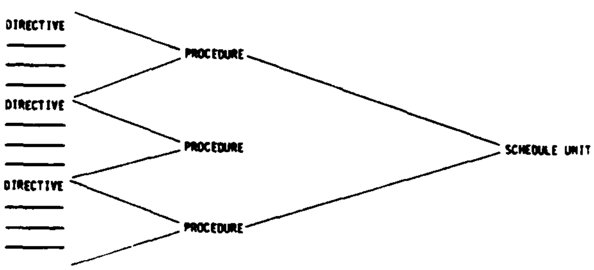


Figure 5. Scheduling Via Procedure Building Blocks

VI. EXTENSIONS TO THE OPERATIONS LANGUAGE CONCEPT

The operations language concept can be extended with benefit into the system design arena. When the set of system directives is developed early enough in the design phase, it provides a convenient road map to trace system end-to-end operation. This is illustrated in figure 6. Frequently, system engineering decomposes the development of a system into hardware and software components and inter-component interface are defined prior to the solidification of the operational uses. What can result is a series of inter-component transmutations of control data, which can increase the complexity and size of a system. If, however, the set of directives is developed and controlled early in the systems engineering process, optimized system interfaces and protocol can be developed. This can reduce system software, interfaces, and provide for a more easily understood system from an end-to-end viewpoint.

The ability to easily trace the flow of control through the system facilitates the system testing processing since the effect of each directive can be traced and analyzed in an orderly fashion as system integration proceeds. At a lower level, unit and string testing can be performed with a high degree of similarity to actual operational conditions.

Significantly, the entire test program can be built by using operational language procedures. These procedures are efficient time savers since by providing repeatable sequences, regression testing is easily performed. The building of test scenarios is easily accomplished via operations language procedures.

VII. MILITARY USER CONSIDERATIONS

An analysis of the profile of the users of modern military space ground systems highlights a trend toward the planned use of Air Force ("blue suit") personnel for operations. This trend, however, brings with it several considerations which make operations language techniques even more important. The Air Force has a built-in turnover rate of approximately 33 percent, due to a basic CONUS three year tour of duty. This turnover level is higher and the required training activity level is higher than in a steadier state environment such as a civil service or a contractor staffed ground system.

The application of an operations language and especially of operations language procedures provides a significant benefit to military space ground systems. Its use permits an off-loading of skill levels by permitting the operations planners (sometimes called "back room" personnel) to develop, test and validate (via simulation) procedures. The system controllers then do not require as much detailed training into the internals of procedures in order to use and execute them. In this fashion the skill, training and even number of operations personnel

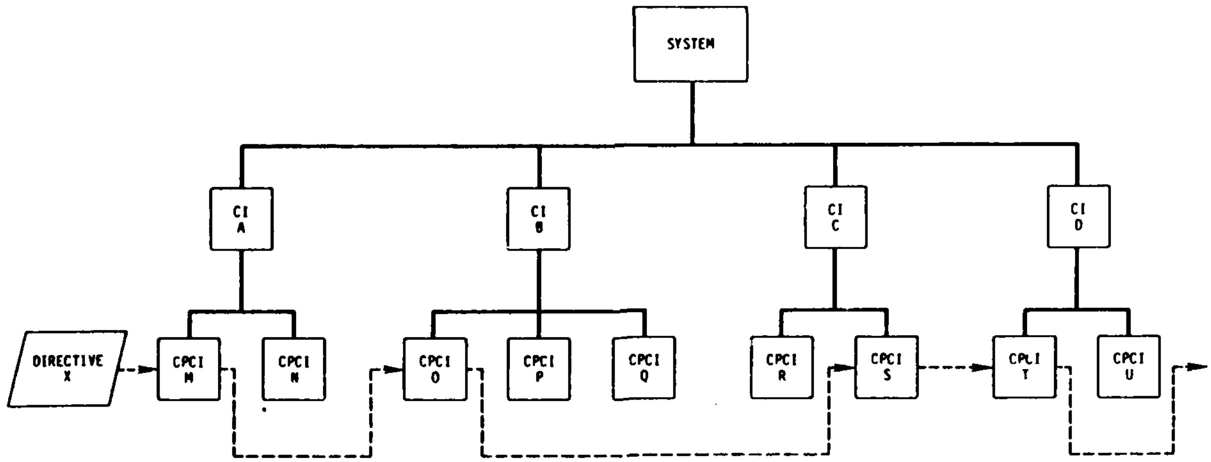


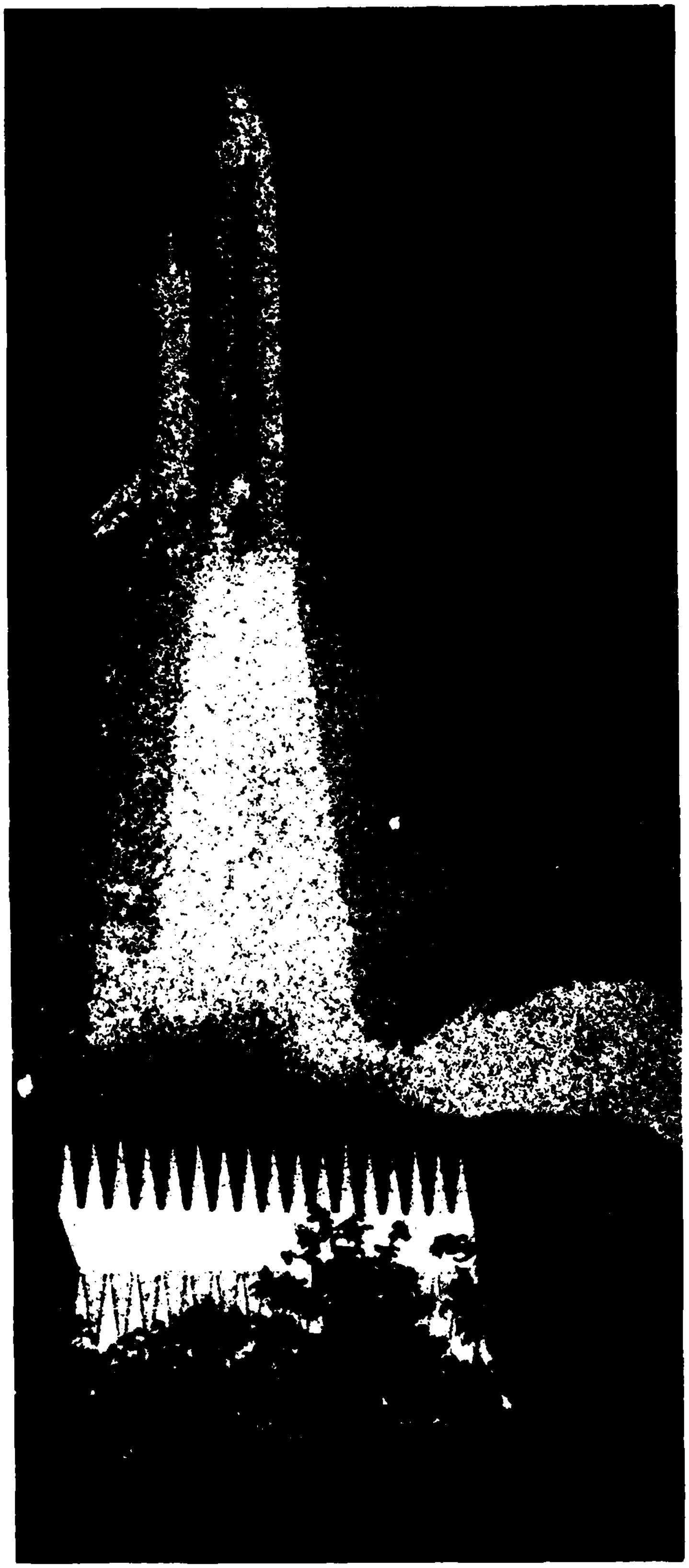
Figure 6. Directive Can Provide End-to-End System Traceability

can be reduced - all contribu‹ing to a reduced life cycle cost. Flexibility of the system is increased, since modification of procedures is easier and less costly than software modifications. This also reduces life-cycle costs.

System effectiveness is increased since in practice, operations language techniques are being coupled with more effective man/machine interface techniques such as pointing, menus, prompts, graphic displays, help techniques, etc. These all compound system effectiveness. System designers are further provided with tools to counteract unskilled typists as users, as well as the ability to balance the significant overload/boredom issue. Procedures also provide excellent tools for handling emergencies, a factor that is also important in reducing errors.

VIII. SUMMARY

The concept of an operations language has involved over the years on several space programs, but has only recently received a formalization with its introduction into the military space ground system environment. The concept involves defining and managing the l est level of system control, deemed the directives. Directives are able to be grouped into stored fixed repeatable sequences which are called procedures. These procedures are able to be used for both normal and contingency operational activities. Procedures are able to be developed and tested by skilled "back room" specialists and their use can reduce operator errors. Due to the need for reduced skill and training levels in the modern military space ground system, the operations language concept can be a valuable tool for system designers and provide a reduction in system life cycle costs.



Session 3

Space System Survivability/Reliability

Session Chairman: J. Hoffman, *Kaman Sciences Corp.*

The Papers

Invited Paper—Satellite System Survivability

Invited Paper—Space System Survivability

Invited Paper—PACSAT: A Passive Communication Satellite for Survivable Command and Control

Reliability in Space: Program Manager and User Awareness

AD P002147

SATELLITE SYSTEM SURVIVABILITY

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ABSTRACT

Present U.S. military capability relies heavily on Earth satellites to maintain connectivity. The essential nature of these satellite systems has made them tempting targets to nuclear attack in wartime. The author reviews U.S. history in high-altitude nuclear device testing and nuclear effects testing on satellites, events in which he directly participated. Physics of the production of nuclear enhanced high-altitude electron belts are reviewed. The author discusses primary effects of the enhanced environment on satellite components. A glimpse into future satellite hardening reveals measures against developing directed energy weapons.

HISTORICAL PERSPECTIVE OF SATELLITE SYSTEM SURVIVABILITY

Three nuclear weapons tests are reviewed which involve satellites and some implications for satellite survivability. The first nuclear tests to be reviewed are the ARGUS I, II, and III events in 1958 and the Explorer IV satellite performance in the trapped radiation belts. From late 1958 to late 1961 there were no atmospheric nuclear weapon tests and during this time a large number of satellites were orbited. In 1962 the STARFISH event was conducted in the Pacific and affected a number of satellites in orbit at that time. The final test to be discussed was the underground nuclear weapon test--HURON KING in 1980 at the Nevada Test Site--on which a special hardened satellite was exposed.

These tests cover briefly the past and present factors bearing on satellite survivability. For future threats, reference is made to a recent study, "High Frontier--A New National Strategy", and in particular to "Chaper II Annex: Survivability of Space Systems".

Dawn of the Space Age

For our purposes, the Space Age begins with SPUTNIK on 4 October 1957. In response to SPUTNIK, the United States formulated the ARGUS exoatmospheric nuclear weapons test for conduct in 1958 with the Explorer IV satellite as the prime measurement system.

The author was Technical Director of the Defense Atomic Support Agency in the DoD, and had operational/contractual responsibility for the conduct of ARGUS and arrangements for Explorer IV from NASA. The newly formed Advanced Research Projects Agency was the overall executive agency for the program.

Exoatmospheric Burst

A nuclear explosion outside the Earth's sensible atmosphere but still within its geomagnetic field, such as at several hundred miles altitude, results in a strong interaction between the magnetic field and the expanding, ionized bomb fragments (Figure 1). The kinetic energy of the bomb plasma is converted into work in pushing aside the magnetic field lines. Bomb debris moving along the magnetic field lines is unconstrained and plunges into the Earth's atmosphere in the conjugate regions, producing intense auroral displays. Relativistic electrons resulting from fission product decay are effectively trapped in the Earth's geomagnetic field and rapidly spread from west to east completely around the Earth, forming an artificial Van Allen belt with many of the same features as the natural Van Allen belts. The ARGUS nuclear explosions, conducted by the United States in 1958, had been designed in late 1957 to produce this trapped electron effect even before the natural Van Allen belts were discovered in the data from the first United States satellite--Explorer 1.

The injected and trapped electron environment from a high-altitude nuclear weapon detonation is one of the most severe nuclear environments for low-altitude spacecraft. Precautions were taken in the design of Explorer IV and its instruments to perform in the predicted artificially produced Van Allen belt. So, from the very beginning, some radiation hardening has been incorporated into our satellite designs.

Last of the Large Yield High-Altitude Nuclear Weapons Tests

Satellite vulnerability to nuclear weapon radiation was most dramatically demonstrated with the 9 July 1962 STARFISH nuclear weapon test which caused failure in about seven satellites from damage that was produced by trapped electrons injected into the Earth's magnetic field by the detonation.

The author was Chief DASA's (DoD) technical representative for planning and conduct operation FISHBOWL in the Pacific in 1962 in which STARFISH was one of five high-altitude tests. The times of the high-altitude test detonations were closely coordinated with NASA to ensure that no important satellites were in line-of-sight of the nuclear bursts. Hence, none received direct nuclear weapon radiations such as x-rays, gamma rays, and neutrons.

For a megaton event (1.4MT) like STARFISH at 400 kilometers altitude above Johnston Island, approximately 10% of the fission spectrum electrons are trapped in the Earth's magnetic field and produce a long-lived radiation belt. The principle damage mechanism was electron produced degradation (premature) and failure of the solar arrays on the satellites as they passed through the trapped radiation belts. Specifically, the satellites Transit 4B, Traac, and Ariel had solar array failures within about a month, and the event caused the eventual failure of Starad, Explorer 15, Injun I, and Telstar.

Concern for the vulnerability of U.S. satellites lead to the Joint Chiefs of Staff issuing in 1968 guidelines to be used as specifications for nuclear hardening of military satellites. The JCS guidelines were subsequently revised in June 1976--and are classified and will not be discussed here.

The U.S. military force structure has become increasingly dependent on satellite systems for navigation, communication, and surveillance. Concern has mounted regarding U.S.S.R. capability and capacity to use an antisatellite (ASAT) system against U.S. spacecraft. This lead to the Presidential Directive in 1978 that orders an increased survivability of U.S. space systems.

In addition to satellite hardening to trapped electron radiation, hardening to the direct nuclear radiation is emphasized. Defense Satellite Communication System II (DSCS II) was the first to have nuclear survivability and radiation hardening included as a contractual requirement.

A principle threat to the ground-based terminals of satellite systems is the EMP produced by high-altitude nuclear detonations. EMP simulations (airborne and ground-based) can effectively test and validate the hardness of the ground-based terminals of satellite systems.

Underground Nuclear Weapons Effects Testing of Satellite Systems

Underground nuclear weapons effects testing provides a realistic simulation environment for validating satellite hardness to direct nuclear weapon radiation. Considerable confidence in satellite hardening technology was gained from the HURON KING UGT in 1980. The test object was STARSAT (SGEMP Test, Analysis and Research Satellite) based on the design of General Electric's defense systems communication satellite - DSCS 3. The HURON KING tests show that radiation hardening techniques used in military satellite designs are effective and that the models used to predict response to nuclear radiation are fairly accurate.

GHOSTS OF FUTURE THREATS

Future space systems must incorporate hardening against the developing Directed Energy technology. Some of the Directed Energy technologies include (besides the conventional weapons systems of kinetic energy pellets):

- High energy lasers (HEL)
- Neutral Particle beams (NPB)
- High power microwaves (HPM)
- Electromagnetic pulse (EMP)

Concepts for eventual hardening of spacecraft systems against Directed Energy threats are in a very early infant stage.

Space-based Directed Energy weapons, if they are ever deployed, will still need to be hardened against nuclear interceptor attack since they will become high-value targets.

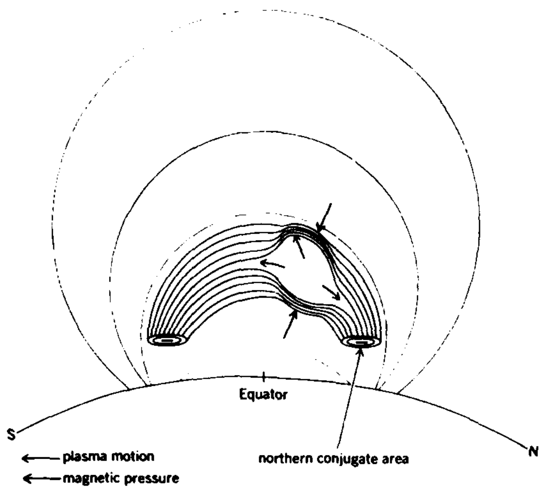

Fig. 1. Schematic showing the early phase of formation of plasma bubble in Earth's geomagnetic field following an exoatmospheric burst.

RELIABILITY IN SPACE: PROGRAM MANAGER AND USER AWARENESS

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ABSTRACT

Space systems and satellite communications are now a reality. As these systems become more important to our military missions, we must ensure we have reliable equipment. The role of reliability is not just the responsibility of the project reliability engineer. The program manager and the user must understand the importance of the reliability program. The designers and users must have a mutual understanding of the program goals. If the engineer is the only one who can understand the system, the user will not agree it is what is needed and the program manager will not support the funding requirement.

RELIABILITY AWARENESS

Reliability is an obvious requirement in space programs. Even as we enter the shuttle era, we still have not fully developed an on-orbit repair capability for our COMSATS. Reliability is not a factor which can be taken for granted by either the program manager or the user. A program manager must be aware of reliability's priority in planning, potential for funding requirements and the necessity for extensive testing. The reliability program can be expensive and is an area where some try to cut costs. What may be a savings for the program manager, however, may be very expensive to the user. "The costs of even a modest interruption of service can far exceed the expense saved by buying the cheapest thing available. Quality and reliability will increasingly be dominating criteria for business as they have long been for the military."(1) This article will address the need for reliability awareness for both the program manager and the user.

What is reliability? There are many definitions. For our purpose, I will simply say, does the system work as specified for the required time. Reliability is not a simple factor. It depends on early planning, effective design, adequate system and component testing, and for many space systems, redundant capability in critical areas. Reliability as an engineering discipline can be very detailed and abstract for someone who has not studied the mathematical equations and simulation models. I am not suggesting that every space program user or program manager should be a reliability engineer. However, a basic awareness of the discipline would be helpful.

Program Manager's Point of View

The program manager is given a multitude of guidance and program directives to follow. DOD Directive 5000.1 and DOD Instruction 5000.2 outline procedures and responsibilities for system acquisition. "The program manager shall be responsible for acquisition and fielding (in accordance with instructions from line authority) a system that meets the approved mission need and achieves the established cost, schedule, readiness and affordability objectives."(2) The areas of readiness and affordability are the key areas relating to reliability. I will address these both through reliability planning. My main concern is the priority of reliability in the design and planning phase. Some may say that we've been building satellites and other space programs with measured increases in success since the 1960s. The lessons learned certainly ensure reliability of our new systems. You might say we have built enough ground radios that this should also be true for new radios. Well, it isn't. During a previous assignment, I worked on a major program that didn't get serious enough about reliability until we were planning

production. We had not ensured performance for the user until we were drafting the production contract request for proposal. There were always hotter fires which required the dollars. Reliability didn't have a high priority. A program manager must consider reliability of a space system at the same level of priority in planning as cost, schedule and as a key element of mission performance. We must look to previous programs, other services and NASA for help. "NASA's philosophy is that reliability is designed in and defects are tested out . . . there is a disciplined and coordinated attack against unreliability on three fronts:

1. Application of effective design principles - and the extensive and meticulous review of designs.
2. Control and screening of all parts.
3. Testing of the entire spacecraft or its prototype for predicted capabilities."(3)

In addition to a reliable design with numerous detailed reviews, the program manager must ensure adequate planning for testing and budgeting. "In its threefold attack on unreliability, NASA has found design to be the most critical determinant of spacecraft performance."(3) While design is critical for the program manager, the reliability problem is not solved with just the design. The affordability factor now must be addressed. Many think it is going to be years before we actually build the system, so we'll just increase the budget next year. That is not realistic or feasible considering the acquisition funding requirements. The designers and program manager must consider the cost of high reliability components, the amount of testing and the cost of special test chambers to simulate space conditions. The Voyager spacecraft had undergone 2000 hours of testing before it was launched(4). You must determine whether any new testing or screening techniques must be developed and what this research will cost. W. J. Willoughby, Jr., as Deputy Chief of Naval Material, Reliability Maintainability and Quality Assurance, has devoted a great deal of time developing the techniques and requirements for the Navy to decrease corporate costs and increase fleet readiness. The Appendix to NAVMAT P-9492, Navy Manufacturing Screening Program, describes a method of random vibration testing for electronic components to reduce cost because test facility cost has become a major obstacle(5). The consideration of special radiation tests and other space environmental factors are of importance in determining the funding requirements for space system acquisition. They are all expensive.

What reliability measures can you afford? "When reliability is defined quantitatively, it is specified, analyzed and measured and becomes a parameter of design that can be traded off against other parameters such as cost and performance(6). The program manager must be aware of all these factors and how they interact with other areas. Reliability and these related facets can be a major portion of the system life cycle funding requirement.

The program manager must include reliability as a high priority starting in Concept Exploration to carry it through the life of a new program. The affordability issue must be looked at from the system life cycle point of view, not from one cycle in the acquisition process. The life cycle costs of a space system are not the traditional acquisition costs plus maintenance and disposal. The opportunity cost must be considered. What is the cost to your mission if the system fails? Can you plan for replenishment launches to continue service? How would a replenishment launch effect other programs? Where is your program in priority for a second launch vehicle? And what would it cost if you had to redirect the contractor's efforts for a replacement system?

What Can The User Do?

You've identified your requirement, now where is your new system? The user needs an awareness of reliability for a number of reasons. First of all, are your availability requirements realistic? With a new system, we always indicate the optimal requirement for fear that they will be cut later. If 99.9% availability is necessary, recognize that this will have an impact on many other factors. Be aware that as users we normally write requirements from a system capability viewpoint (i.e., number of channels, system availability, etc.), not from a design interrelationship viewpoint (i.e., redundancy vs. weight). The end product is a combination of many factors. As we all realize, we do not have forward supply points in space. To achieve your mission goals, the design may require extensive redundancy. Redundancy will affect weight, which could limit your requirement for a specific number of channels. The particular launch vehicle weight limit must be added to this assessment. Another factor to consider is your initial operational capability (IOC) requirement. Will your IOC support the time required for the extensive testing necessary to ensure reliability?

As a user, become involved early. Have the right people attend early design reviews. Designate someone to be a member of the reliability group. Don't make this the person's third or fourth additional duty. The user must also give reliability the priority it deserves. Select someone who will provide continuity to the program as it develops. Be flexible and realistic. Recognize the problem areas and be willing to work out tradeoffs with the program manager. There is no one answer for every program. As a user of a space program, communications or otherwise, your mission is depending on reliability.

Many program managers prefer to keep the user as far away from program office business as possible, until turnover. I feel if you are informed and aware of the importance of reliability planning, you can be a valuable asset to a program manager. Reliability is only one area where we need a unified voice from the program manager and the user to present the program to Air Staff. If the developers clearly understand and can provide what the user wants, and the user understands and can support the design logic, the program is on its way to success. A cooperative approach can alleviate side battles within the program family, allowing more energy to present a unified program through the approval channels.

Conclusions

Reliability cannot be assumed as just another operational requirement. The program manager and the user must be aware of the importance and priority in planning. Even with the proper planning, the degree of reliability required in our space programs could make reliability the most costly part of the program. If it is not given a high priority early and planned for in each future phase of the program, it could be our biggest stumbling block. We must all be aware of the implications of reliability and plan early.

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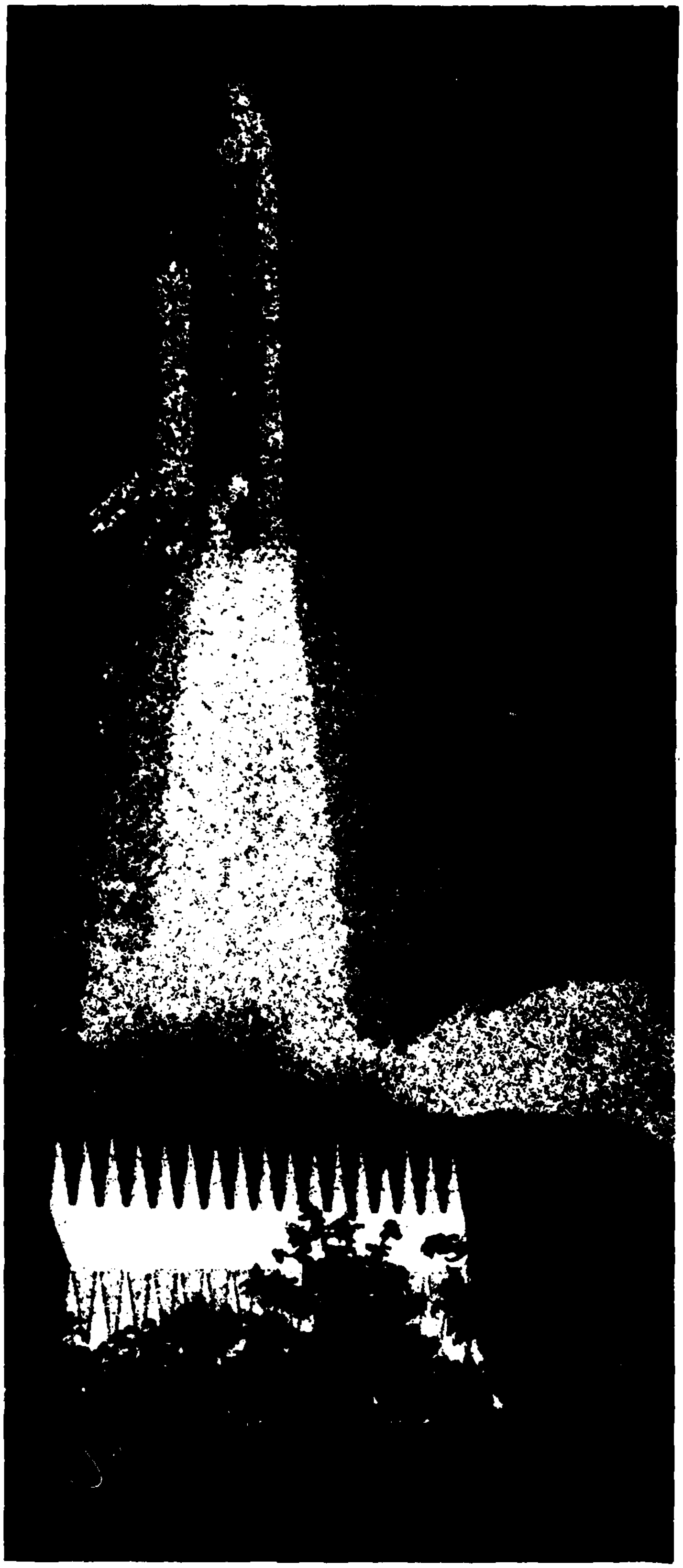

Session 4

Space System Technology/Analysis

Session Chairman: Lt Col A. J. Rosa, *USAFA*

The Papers

Invited Paper—The Evolution of Air Force Space Mission Command, Control and Communications

Operation of Communications Satellite Systems During Crisis and Conflict

Command Post Modem/Processor (CPM/P)

RF Design and Performance of a Multibeam, Multiband Antenna

THE EVOLUTION OF AIR FORCE SPACE MISSION COMMAND, CONTROL AND COMMUNICATIONS

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ABSTRACT

This paper traces the evolution of Air Force space mission command, control, and communications as the Air Force Satellite Control Facility has matured and as the Space Shuttle becomes operational. The internetting of Air Force and NASA support networks is described, as exemplified by the development of the Consolidated Space Operations Center. Recent trends toward an evolutionary methodology for acquiring space command and control systems are also discussed.

INTRODUCTION

Acquisition and implementation of new capabilities for Air Force space command, control, and communications are typically thought of as a series of "new starts" that provide unique, program-specific capabilities. In actual fact, for the past twenty years USAF satellite tracking, telemetry, and command (TT&C) development has been much more of an evolutionary process, with new capabilities being added to the satellite support network to meet the common needs of a number of users.

Manned spaceflight support has tended, at least through the Apollo mission series, to follow the "typical" new-start development methodology. However, the advent of the Space Transportation System (STS) as the first truly operational US manned spaceflight program has led enhancements to the STS ground support network to follow a much more evolutionary path.

Another significant phase in the evolution of these support networks has resulted from recent emphasis of national space policy on network survivability, support flexibility, and maximum operational efficiency. This phase is the internetting of common-user Air Force facilities, previously-dedicated Air Force facilities, and NASA facilities into an integrated Space Control Network, perhaps best exemplified by the development of the Consolidated Space Operations Center (CSOC).

This evolutionary approach to new capabilities has now been extended to the acquisition methodology used in systems development. First, competitive definition or design contracts are used in the selection of a development contractor. Next, after contractor selection, development contracts feature an incremental, or block, approach, which provides flexibility of implementation within tight fiscal constraints.

EVOLUTION OF SATELLITE CONTROL

1960. The Satellite Test Center (STC) is activated on an 11.4-acre site in Sunnyvale, California. The STC is linked to four tracking stations through 1.2 kilobit-per-second landline communications. That year, a total of 300 TT&C contacts with satellites are supported by the STC.

1982. The Air Force Satellite Control Facility (AFSCF) consists of multiple Mission Control Complexes (MCC's) at the Sunnyvale site, linked to twelve Remote Tracking Stations (RTS) through wide-band (up to 1.5 megabits-per-second) satellite communications. Simultaneous TT&C contacts with twelve spacecraft is the rule. Almost 95,000 contacts are supported during the year.

A 300-fold increase in satellite support with only a 3-fold increase in the number of tracking antennas which actually contact spacecraft is of itself a remarkable achievement. Even more significant is the trend in support requirements as shown in Figure 1: spacecraft support workload has

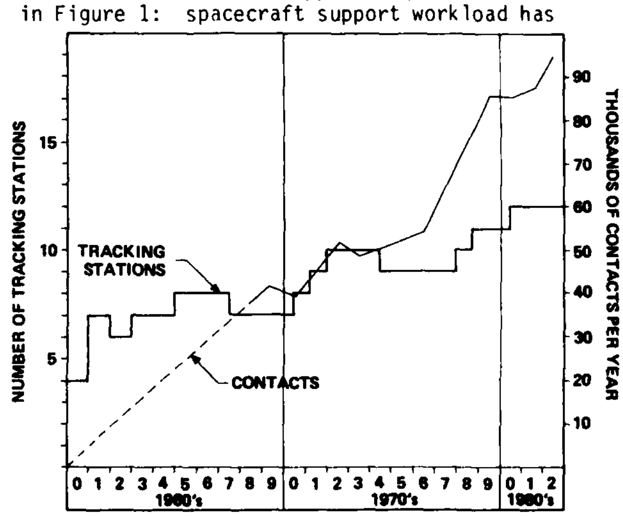

Figure 1. The Increasing AFSCF Workload. Number of contacts per year are estimates through 1967, actuals thereafter

increased nearly monotonically throughout this 22-year span. The AFSCF has thus been forced to implement network enhancements in an evolutionary fashion in order to maintain ongoing operations while preparing for increased supoort requirements.

Early Enhancements

Early AFSCF network enhancements focused on increasing the number of remote tracking sites, augmenting RTS equipment complements, and increasing the number of control consoles and computers within the STC control room. The primary objective of these augmentations was to provide the capability for multiple TT&C 'control paths' from the STC through the RTS's to supported spacecraft, thereby permitting multiple simultaneous contacts. The first successful multiple satellite operations were conducted in support of the Discoverer program on 17 February 1961. By the end of 1963, such operations were routine. Subsystem improvements included RTS Precision Long Range Tracking Radars and display equipment at both the RTS and STC. Figure 2 shows the 1964 system design.

Standardization

Although the enhancements described above substantially increased AFSCF support capability, early RTS's were still for the most part individualized. No two stations were identically configured, and a variety of TT&C systems were used to match the peculiar requirements of each spacecraft being supported. Such uniqueness obviously limited the support flexibility and efficiency of the total network; it also was increasingly expensive. In recognition of this problem, the Air Force conceived the concept of an integrated, standardized TT&C system for DoD spacecraft support: the Space-Ground Link Subsystem (SGLS). Implemented in the 1967-9 time frame, SGLS multiplexed TT&C signals on RF carriers in the 1.76-1.84 GHz (uplink) and 2.2-2.3 GHz (downlink) frequencies, allowing use of a common antenna for uplink and downlink transmissions. Greater uplink and downlink capacity was achieved, and satellite tracking accuracy was significantly improved. In conjunction with SGLS, an Advanced Data System (ADS) was implemented. ADS equipment installed at the RTS's included a new computer system, improved display and control equipment, and new interface equipment to mate ADS with existing RTS systems. The STC was expanded to include a modernized (CDC 3800) computer system and a new display and control system, thus allowing satellite controllers at the STC to exercise direct control over their missions.

Two other implementation steps in the late 1960's furthered the standardization process. All STC elements of control for a particular program

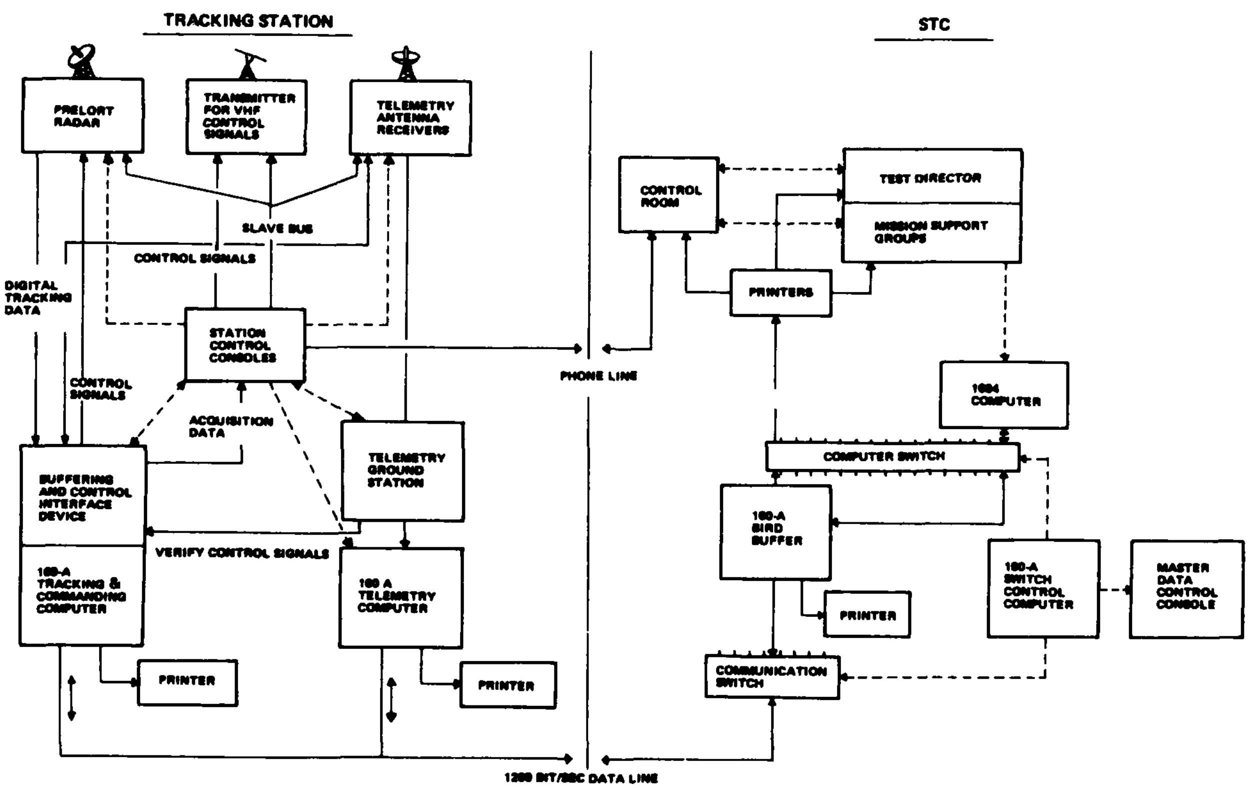

Figure 2. AFSCF System Design Circa 1964

or set of programs were consolidated in Mission Control Complexes, each of which had the necessary system and personnel resources to support planning for and control of assigned missions. Secondly, a centralized Scheduling Control and Resource Allocation Buffer Link (SCRABL) program was developed to provide a complete schedule of all AFSCF activities at both the RTS's and STC. SCRABL-produced, detailed, 7-day schedules provided greatly improved integration of system maintenance and modification efforts into the total AFSCF activity flow, significantly increasing the system availability for satellite support operations. The scheduling function was part of a centralized Range Operations organization, charged with controlling "common-user" AFSCF resources (e.g., the RTS's) and providing network services to all MCC's. The 1970 AFSCF had thus virtually isolated program-uniqueness to the MCC's, with standardization of other network assets for maximum responsiveness. Figure 3 shows the 1970 system design.

Meeting the Megabit Challenge

The 1970's might be termed the satellite Information Explosion Era for the AFSCF. Advances in spacecraft mission sophistication and satellite technology led to great increases in data rates, which the AFSCF was required to route and process in real-time or near real-time. (Such data was previously processed at the RTS and relayed to the STC at 1.2 kilobits per second, with obvious implications on data freshness.) A limited capability for real-time data transfer was obtained in 1972 through implementation of an Interim Wideband Communications System (IWCS), which linked the Guam and Hawaii tracking stations to the STC through the Defense Satellite Communications System (DSCS). Real-time relay of analog data at one MHz could be achieved.

A much more comprehensive wideband communications upgrade effort was begun in 1975, bearing the somewhat cumbersome name of the Defense Satellite Communications System/Satellite Control Facility Interface System (DSIS). DSIS employed asynchronous multiplexer and demultiplexer equipment to combine signals from a variety of sources (at either the STC or RTS), then to modulate or demodulate the combined signals onto or from 70 MHz interface carriers relayed through the DSCS satellites. Upon completion of the DSIS program in 1978, digital data could be forwarded from the STC to an RTS at up to 192 Kb/s, and returned from the RTS to the STC at up to 1.53 Mb/s.

One significant advantage of DSIS implementation was the capability to centralize TT&C data processing at the STC, rather than having to split processing functions between the STC and RTS's. However, the CDC 160-A 'Bird Buffer" telemetry processing computers at the STC were incapable of

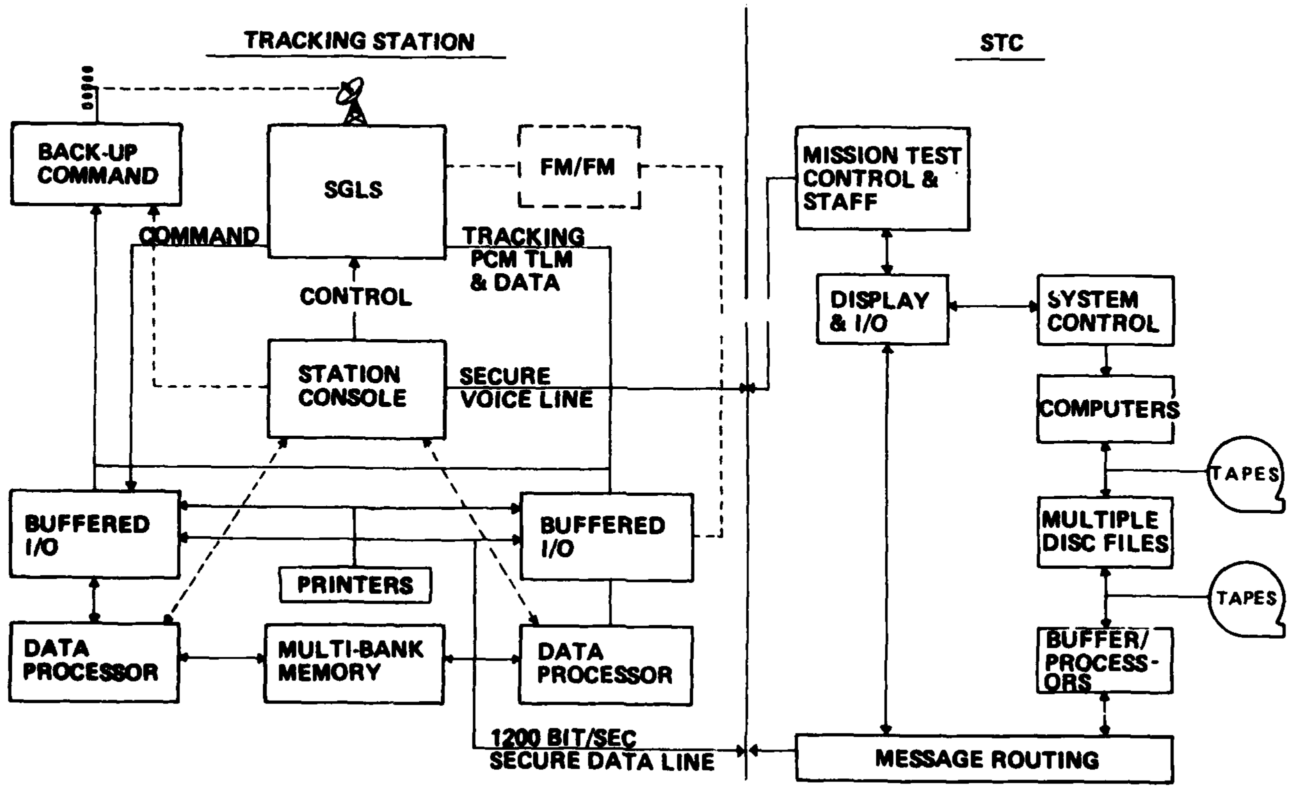

Figure 3. AFSCF System Design Circa 1970

providing the throughput necessary to do the total processing job. In parallel with DSIS implementation, replacement of the 160-A computers was undertaken. A key ground rule of the replacement process was preservation of the several million words of code being executed on the 160-A's--recoding was unacceptable both from cost and operational risk viewpoints. The resulting replacement design featured a Varian 73 microprogrammable processor which emulated the logic of the predecessor CDC machines, thus preserving the code, while achieving 7:1 improvement in processing throughput. This design provided computing capability within the STC fully compatible with the higher data rates of DSIS.

The Future: Automation

By 1979, the above evolutionary enhancements allowed the AFSCF to provide near-flawless support of greatly increased satellite support requirements. However, network operations continued to be manpower-intensive. Support projections for the 1980's and 1990's also indicated network saturation was rapidly approaching. The AFSCF therefore undertook a sweeping TT&C modernization effort in 1979. This program, termed Data Systems Modernization (DSM), has as its key requirements:

- Centralized data processing
- Modern flight support hardware systems
- Modern, ADA-based software development
- Simplified operations for reduced staffing

DSM hardware and software development is currently underway, with MCC initial operational capabilities scheduled to be phased in throughout the mid-1980's. When completed, DSM will allow current STC and certain current RTS TT&C operations to be fully controlled from individual MCC's. Automation of network resources scheduling is also planned. Finally, a parallel modernization of the RTS's is planned for the mid-1980's to further automate RTS operations. Exhaustive Air Force planning for these efforts has focused on carefully phased transition to modernized systems, to ensure that new capabilities will be brought online without impacting continuing operations.

MANNED SPACEFLIGHT EVOLUTION

In contrast to satellite operations, manned spaceflight support through the Apollo era may be fairly characterized as a series of 'new start' developments. A substantial base of software applications code (e.g., trajectory analysis) has been used with modest modification throughout the Mercury, Gemini, Skylab, Apollo, and early Space Transportation System (STS) programs. Similarly, some hardware legacy was maintained. However, each of these programs had unique mission objectives which were reflected in significantly dissimilar TT&C support requirements and accompanying systems at NASA's Johnson Space Center (JSC).

The STS System, however, was from its inception planned and implemented as a truly operational launch vehicle capability with a series of evolving objectives:

- Operational capability for single flight support
- Dual flight support capability
- The capability to support secure DoD flights (termed "Controlled Mode")
- The capability to support sophisticated on-board experiment packages from a "Payload Operations Control Center"

To meet the requirements of these four operational phases, JSC ground control capability has been planned for and is being implemented in a series of evolutionary steps.

Figure 4 shows the increase in one area of STS operations, flight display, control, and communications functions, as STS operations evolve from single-flight control through payload operations. As was the case with the AFSCF, the basic philosophy of STS modernization throughout this period has been the preservation of existing equipment and software while developing new capabilities. The example of Figure 4 is mirrored by equivalent evolutionary increases in the technical equipment and supporting software required for other flight control functions; for flight planning; and for flight preparation activities such as simulation. Through such evolutionary modifications, NASA has been able to continue to plan for and execute successively more complex missions, while retaining operational capability to fully support current mission efforts.

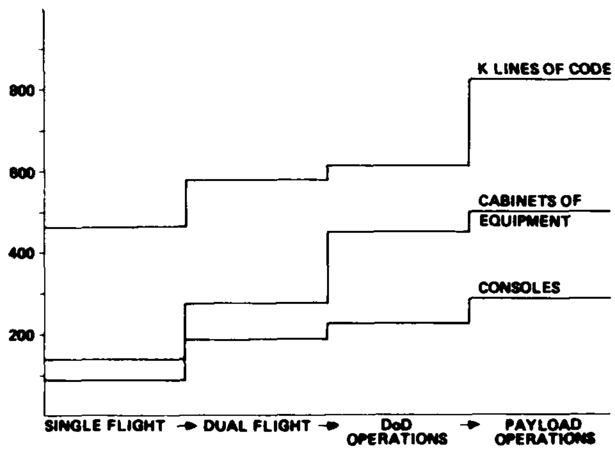

Figure 4. Operational Evolution of STS Flight Control, Display, and Communications

INTERNETTING

Historically, the development of Air Force and NASA space support systems has been kept separate as a matter of national space policy. With the advent of the STS as the common launch vehicle for both DoD and NASA spacecraft, it became appropriate to combine NASA and Air Force Space Mission support assets into a truly common user network for all United States space programs.

Initial efforts to combine Air Force and NASA control systems focused on the use of Air Force facilities to support the initial phases of the STS program. Specific modifications to the Air Force's Electronics Systems Test Laboratory and the Remote Vehicle Checkout Facility (RVCF) at Kennedy Space Center (KSC) were made to permit detailed pre-launch Space Shuttle and Space Shuttle payload compatibility testing. Major modifications were also made to both the STC and to all RTS's to enable shuttle TT&C support to be provided through both the AFSCF network and NASA's Ground Spaceflight Tracking and Data Network (GSTDN).

Figure 5 shows the internetting of Air Force and NASA Control networks created by these initial modifications. Support of DoD and NASA satellites remained the separate responsibilities of DoD and NASA networks. The Vandenberg Air Force Base (VAFB) and KSC launch control complexes (called "LCC's" at Kennedy and "SLC's" at Vandenberg) continued to serve both DoD and NASA launch missions. The key new internet was an STS TT&C path from the RTS through the STC to NASA's space mission communications center at Goddard Space Flight Center (GSFC), then on to JSC. Successful implementation of this new NASA-DoD interface allowed NASA Mission Controllers significantly enhanced TT&C access to the Shuttle during critical mission phases.

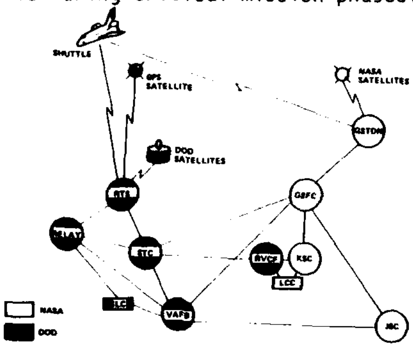

Figure 5. Air Force - NASA Control Network Internetting Circa 1981

The next major STS modification to the AFSCF was the development of the Inertial Upper Stage (IUS) Mission Control Center at the STC. The IUS was developed by the Air Force as a booster stage to allow payloads, initially launched from the Shuttle, to reach higher orbital altitudes. With the IUS MCC operational, Air Force and NASA control networks could cooperatively support satellite missions throughout the launch, boost, and on-orbit phases. An excellent example of such multi-network support capability is the 1983 launch of the Tracking and Data Relay Satellite System (TDRSS). The TDRSS satellite, basically a NASA asset, was launched from a NASA Shuttle, and boosted into orbit on an Air Force IUS. Throughout the flight of the Shuttle, the IUS, and the TDRSS satellite itself, both Air Force and NASA ground-control networks were actively involved in following the progress of the TDRSS mission. The TDRSS flights also demonstrated the capabilities of direct wideband data links developed between the STC and NASA's Johnson Space Center (JSC), as well as the development of shuttle telemetry data processing capability within the STC.

Development of the Air Force Space Control Network (AFSCN)

Continued internetting of NASA and Air Force assets was obviously an effective and efficient way to combine previously separate capabilities into an integrated space mission support system. In addition, certain functions of previously dedicated satellite systems showed promise for "common user" applications to multiple satellite support. The resulting integrated space support network has been termed the Air Force Space Control Network (AFSCN). The AFSCN combines assets of the AFSCF, of NASA, and of previously dedicated networks such as the Global Positioning System (GPS) into a truly integrated space support network.

The heart of the AFSCN is the Consolidated Space Operations Center (CSOC), to be located near Colorado Springs, Colorado. Figure 5 showed the limited internet of Air Force and NASA space assets in the 1981 time frame; Figure 6 redepicts the network in the 1990 time frame, with the CSOC operational. The CSOC itself consists of both a satellite control center (analogous to the current STC), and a secure DoD shuttle support capability. CSOC communications systems link the facility to both current Air Force and NASA tracking networks, including the TDRSS system. In addition, the facility has been designed to accommodate such dedicated satellite support systems as GPS and the new MILSTAR communications system. Through the internetting of such dedicated systems with the common user network of the AFSCN, greater operational flexibility and significantly improved survivability of these dedicated networks is provided. When operational requirements of the dedicated networks permit, assets of those networks may also be used to further enhance the common-user capabilities of the AFSCN in supporting other satellite programs.

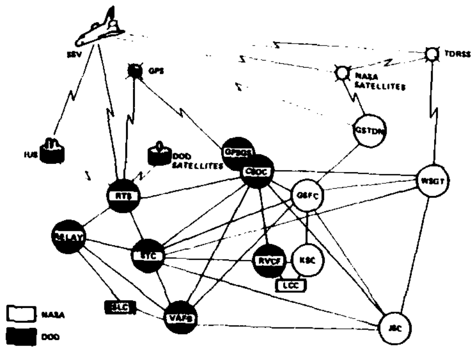

Figure 6. The Air Force Space Control Network Circa 1990

EVOLUTIONARY PROCUREMENT METHODOLOGIES

The evolution of the space support systems described above has significantly enhanced the overall interoperability and utility of all U.S. space systems. The cost, however, of space C^3 development has been of continuing concern to the Air Force--in particular, major cost growth during development as a result of requirements changes. Under the guidance of both General Slay and General Marsh, as commanders of the Air Force Systems Command (AFSC), a major effort has been undertaken to procure space C^3 systems in an environment of maximum competition and minimum cost-growth. Two specific procurement strategies have been used:

- Use of a procurement procedure, described in OMB Circular A-109, which involves competitive definition or design study phases before development contract action.
- The use of a block or incremental support capability strategy in development contracts to allow incorporation of evolving requirements with minimum cost impact.

The "A-109 type" procurement methodology is an approach of two-or-more phases. It is modeled after the procedures established by DoD for the procurement of major weapons systems. The principle behind the A-109 methodology is to fund two or more contractors for the competitive development of a weapons system prototype to satisfy a given requirement or mission need. When a subsequent single production contract is awarded, costs are known and risk, technical as well as cost and schedule, is substantially reduced.

When associated with space C^3 programs, the A-109 type definition or design procurement results in development of specifications, plans, and design concepts rather than a prototype. Once the chosen definition phase contractors have completed their tasks, the Government has the capability of melding the results into an improved specification for the development phase RFP. The Air Force therefore gains the expertise of all definition phase contractors in analyzing requirements and design alternatives. Resulting development phase proposals therefore provide increased confidence in validity of the technical approach and the accuracy of costs.

The second major strategy of the evolutionary development approach is the implementation of major space systems in a truly evolutionary manner. A basic capability is contracted for in the initial phase of a development effort, with subsequent capabilities planned as options to the basic contract. Through the use of such options (termed "blocks" or "incremental support capabilities"), the Air Force has the opportunity to observe development contractor performance and to verify long-term requirements before commiting to significant additional expenditures for complete capability development. This combination of A-109 procurement and incremental development contracting has been used or is being contemplated for use by AFSC in the DSM procurement, in the CSOC Communications contract, and in the CSOC Shuttle Operations and Planning Complex contract.

The basic advantages to the Air Force of the use of A-109 and block development approaches to space support C^3 programs are obvious. The definition segment allows the Government to identify program risks, stimulate competition, and gain the best technical solution for a given set of requirements. The development segments allows for an early initial operational capability, for continued analysis of high risk requirements, for the capability to infuse technology as it becomes available, for more adaptable funding profiles, and for continued evolution of the required capability over a much longer time span. There are, however, challenges to both the Air Force and contractor community when this methodology is applied. In a multiple-contractor definition phase effort, Air Force technical monitors must be careful to maintain the proprietary nature of innovative technical solutions and prevent "technical leveling" between competing contractors. Additionally, a manpower burden is placed upon the Air Force to maintain full awareness of multiple competing design efforts. From the contractors viewpoint, a careful balance of effort is required between performance of definition phase tasks (e.g., specification development) and preparation for the development phase competition. Once the development phase contract itself is awarded, both the Air Force and the contractor must work closely and cooperatively together to insure that changing requirements, when identified, are implemented in the appropriate block or incremental support capability to provide a truly cost and technically effective solution.

CONCLUSIONS

The evolution of Air Force space mission support C^3 has a rich history and a promising future. As Air Force and NASA ground and space assets are melded into a truly national space system, significant opportunities exist for technical innovation and cost effectiveness in the satisfaction of national space objectives. These opportunities are matched by equally significant challenges to efficiently implement change without degrading ongoing operations. Changes in acquisition methodologies provide additional challenges to both the contractor community and the Air Force; but working together, the Air Force-contractor team shall continue to do what it has done in the past--get the job done, and get it done right.

OPERATION OF COMMUNICATIONS SATELLITE SYSTEMS DURING CRISIS AND CONFLICT

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ABSTRACT

U.S. military communications satellites can provide an impressive capability for command and control. Whether the combat forces will be able to make effective use of this capability depends on the operational management of the systems. Today, control of COMSAT systems optimizes their use to support a single mission or class of missions. In conflict it will be necessary to allocate capacity based on mission priority rather than peacetime operational concepts. A satellite control network tied to the JCS through the Space Defense Operations Center would allow rapid reallocation of capability to support wartime and crisis requirements without jeopardizing the role of the operational manager.

INTRODUCTION

"The Navy has the finest peacetime communications system in the world, through the FLTSATCOM system." This oft repeated claim highlights both the strength and the weakness of military satellite communications (MILSATCOM). They are effective, reliable and efficient. We have seen the Fleet Satellite Communications (FLTSATCOM) system bring word of the shootdown of two jets over the Gulf of Sidra to the Chief of Naval Operations within two minutes of the attack -- exactly what the Navy intended of the system when they wrote the specifications more than a decade before. We have seen the Air Force Satellite Communications System (AFSATCOM) allow Headquarters Strategic Air Command maintain positive control over a B-52 participating in an exercise halfway around the world. We have seen the Defense Satellite Communications System (DSCS) revolutionize the handling of wideband data between overseas locations and the United States. In these and countless other applications we understand our systems and are experienced in making them perform as required.

On the other side of the operational coin, we have little experience operating the systems under stressed conditions -- conditions where the satellites are being jammed, or there is a sudden decrease in capacity available or increase in demand for support. Peacetime performance is certainly essential, and obtaining more bits for the buck is as important to a communications system as more bang for the buck is to a weapon system. But the reason for military acquired, owned and operated systems is their ability to perform in crisis or war. Without that, we might as satisfy all our long haul SATCOM requirements with leased commercial satellites and terminals.

Future SATCOM systems such as the *Military Strategic, Tactical and Relay* (MILSTAR) system are being designed to provide service in a hostile environment. The anti-jam capability of DSCS III is a substantial improvement over anything in the inventory, and with the spread spectrum modem will offer assurance that the minimum essential communications between heavy terminals will get through -- once all the satellites and AN/USC-28 equipment are in place. These projections, however, don't help the warfighter today.

We learned during some of the crisis and contingency operations of the last five years that the systems we have can do things the original designers never expected, when operated with imagination and careful planning. The challenge facing the MILSATCOM operator is to make this crisis capability available on a rapid basis without disrupting the rest of the system, including high priority peacetime users, to an unacceptable level.

This paper will review the operational concepts for MILSATCOM

systems in general and for the three primary systems: AFSATCOM, FLTSATCOM and DSCS. It will assess how they might perform if pressed in a crisis or wartime situation, and propose how this capability could be improved at little cost. I appreciate the assistance of the Operational Managers (OM) for the three systems, and of the Army Satellite Communications Agency for supplying data on the Ground Mobile Forces SATCOM system. I am sure there are cases where I have taken good data and either misunderstood or wrongly applied what was said. The responsibility for these errors is mine.

CONTROL OF MILSATCOM SYSTEMS

JCS MOP # 178: "MILSATCOM Systems"

The primary policy guidance for operations of MILSATCOM systems is the JCS Memorandum of Policy Number 178, "Military Satellite Communications Systems". This guidance has evolved over several iterations to keep pace with the improvements in SATCOM systems. The 1978 revision, which is the most current version, defines the responsibilities of the operational managers and the Joint Chiefs of Staff (JCS). The JCS retains the authority to approve and direct support to new users in crisis or war, while the OM is allowed considerable latitude in peacetime, and in the manner in which additional users are included in crisis or war. In general, the MOP prioritizes allocation of capacity in the following order:

1. National Command Authorities
2. Joint Chiefs of Staff
3. Commanders in Chief (CINCs)
4. Component Commands of CINCs
5. Other operational forces
6. Other users

MILSATCOM systems are divided into two types, those under the control of a single military department, called "Service-managed" and those under joint control, or "Joint-managed". The only Joint-managed system is the Defense Satellite Communications System (DSCS) which is operated by the JCS through the Defense Communications Agency (DCA). The Service-managed systems are AFSATCOM operated by the Air Force, FLTSATCOM operated by the Navy and the Ground Mobile Forces (GMF) system operated by the Army. Each Service has designated an Operational Manager for day-to-day control of the systems (Air Force Communications Command / Strategic Communications Division, Naval Telecommunications Command and US Army Communications Command, respectively). These organizations respond to Service direction, or to the JCS in stressed situations when new users are added to the system. Under these conditions most new users would be considered "JCS requirements" with Priority 2, and would preempt lower priority peacetime traffic unless there was sufficient excess capacity to accomodate the demand.

The next section will describe the control procedures used by the various operational managers to manage crisis situations. The GMF is developing its own control system, but at this time relies on the DCA control network. GMF will not be discussed as a separate element.

CONTROL IN CRISIS

AFSATCOM

The management for AFSATCOM flows from the JCS to the Chief of Staff, USAF as the Executive Agent, then to Air Force Communications Command and the Strategic Communications Division as Operational Manager (OM). The OM has published the operating procedures in a "System Operating Policy and Procedure" (SOPP) which has been distributed to all the unified and specified commands, joint agencies and several hundred service organizations. The SOPP describes the categories of users as Approved and Unapproved, and within the first group as Full Period, Scheduled and Unscheduled. An organization with crisis responsibilities, such as the Joint Communications Support Element, would be carried as an Approved Unscheduled user -- someone who had an operational concept approved by the JCS and included in AFSATCOM planning, but couldn't predict in advance when, where or in what quantity capacity would be needed. The OM carries all the necessary technical information in its data base, and can accomodate requests for service on short notice without any additional JCS involvement.

Unapproved users are those whose intended use of the system has not been formally approved. This may be because they are an R&D organization with infrequent demands, or because they are responding to a crisis which requires satellite communications under conditions that had not been foreseen. The SOPP provides for telephone coordination of emergency requests, and for support in accordance with the priorities in MOP 178.

The system design for AFSATCOM includes single access and multiple access channels. The 5 khz narrowband (NB) channels are half-duplex and can support only one user at a time. Several terminals can share the channel, but only on a time-division multiple access basis. This TDMA can be automatic if the terminal is equipped with the proper control modem, or based upon user dicipline. In either case, because of the low data rates available (75 bps) the most common means of allocation of NB capacity is to assign a full channel to a network or sub-net. Because the satellite is channelized with specific power allocations for each channel, the user is assured of both bandwidth and EIRP.

Recent work by SCD has demonstrated the ability to support higher data rates on some of the NB channels on FLTSATCOM. While this probably won't affect the concept of assigning single nets to channels, it may alleviate possible conflicts on the wideband channel.

Each FLTSATCOM satellite carries one 500 khz channel in addition to the 12 NB AFSATCOM channels and 10 25 khz Navy FLTSATCOM channels. The primary use of the 500 khz wideband (WB) channel is to support multiple 75 bps teletype links. All AFSATCOM command posts are equipped with 8-ary FSK modems, and the channel can support at least 14 half-duplex accesses simultaneously in the absence of other channel users. Competition for the channel arises because it has high power and enough bandwidth to support high data rate communications. However, the design is such that downlink power is allocated among links in proportion to the uplink power -- hence a small number of high power, high data rate users can "crowd out" other links. The situation is not much different from that faced by DCA in allocating access to the DSCS satellites.

The assignments of users to the WB channel is done in the same manner as for NB, and the channels are monitored to ensure terminals are operating at the proper power and frequency. Because of the flexibility of the WB channel -- virtually any UHF terminal operated by the US military can be used -- it is in constant demand for unscheduled users. Most obtain authorization before using the system, but some do not. This points out one of the most difficult problems in SATCOM management: it is difficult to monitor access, difficult to locate unauthorized users, and short of a physical attack nearly impossible to force someone off the system. The multi-beam antenna of DSCS III will help solve the problem for that system, but for earth coverage systems such as AFSATCOM and FLTSATCOM the Operational Manager is nearly helpless.

Of the three major MILSATCOM systems, AFSATCOM has the most experience in supporting crisis and other unscheduled requirements. This is partly because the system is flexible, and can be used by any UHF SATCOM terminal. However, it is also because the system was designed with some excess capacity. This excess is not a matter of gold plating: under certain conditions every channel of every satellite in sight of critical strategic areas would be filled. These conditions drove the design, because the wartime requirements for global strategic command and control are the reason the system was built. Since the situations which would saturate the system would almost never occur in peacetime or crisis, the OM has some flexibility to apportion the available channels to other users as long as he can assure the Approved Full Period and Scheduled users the system will be available when they need it. Much of the development of operational contingency terminals has been a result of success in using AFSATCOM capability in exercises and demonstrations of crisis response.

Because of the experience in dealing with unapproved high priority users, AFSATCOM is more likely than DSCS or FLTSATCOM to be able to handle without major disruption the rapid changes in operations which would be likely in a crisis. Whether this will continue to be the case as more approved users are equipped with terminals and the system fills up in peacetime remains to be seen. The SOPP suffers from the imprecision of MOP 178 in that it will be difficult to prioritize among "high priority" users. If many of the crisis users have terminals which require large shares of the satellite power and high data rates which force them to the WB channel -- as is likely since this describes as portable secure voice system -- the confidence of the OM in preparing for crisis operations may soon erode.

FLTSATCOM

The FLTSATCOM is the oldest of the service-managed systems. It includes terminals on board all Navy ships and many shore facilities. The space

segment includes channels on the four FLTSATCOM satellites, GAPFILLER and eventually LEASAT. The operational concept of FLTSATCOM is much like that of DSCS in that the users who are on the system in peacetime are assumed to be the same as those in crisis or wartime. From a technical viewpoint, the system is more like AFSATCOM in that channels are assigned to specific networks, and have protected EIRP and bandwidth.

The OM for FLTSATCOM is the Navy Telecommunications Command (NAVTELCOM), with the CNO as Executive Agent. In many respects FLTSATCOM is operated as a part of the general purpose Naval Telecommunications System (NTS). It is tied into several automated information exchange systems, and the focal points for day-to-day operations are Naval Communications Area Master Stations (NAVCAMS).

Because FLTSATCOM is so essential to peacetime communications among ships and ship-to-shore, there is little planned flexibility to accomodate other users. All channels on all satellites are assigned to a specific mission: Fleet Broadcast, Command Ship Secure Voice, Common User Digital Information Exchange System, Tactical Intelligence Subsystem, etc. Nevertheless, the Operational Concept and Procedures (NTP-2) acknowledges that "there will be occasions when some manipulation of SATCOM capabilities and services will be required to respond effectively to the demands for service generated by crisis/contingency operations". The manner in which the manipulation will take place depends on whether the requirements are Navy or non-Navy.

The Fleet Commander in Chief, e.g., CINCPACFLT, is responsible for direction and support of naval forces operating at sea. This includes some tactical communications functions performed by NAVTELCOM. In the case of FLTSATCOM, the NAVCAMS which control each satellite operate under the direction of the theater FLTCINC. Within limits described in the operating procedures, the FLTCINC is authorized and responsible to make adjustments to the system to support changes in Navy requirements. This may include preemption of circuits, activation of spare terminals or off-loading networks to other satellites.

The situation for non-Navy requirements is not so clear. To quote NTP-2, "It can be anticipated, however, that under certain crisis conditions, the Navy will be tasked to provide services, in accordance with JCS MOP 178, to support requirements of the NCA, JCS, Unified Commanders, or others. The support of such unforeseen requirements may require the temporary preemption and reallocation of one or more FLTSATCOM channels or GAPFILLER accesses. To minimize the impact on Navy subscribers, the precise manner in which such non-Navy requirements are to be satisfied will be determined by CNO in close coordination with COMNAVTELCOM and appropriate FLTCINCs."

This approach highlights the problem facing the Navy or any other OM who waits until a crisis arises to publish and exercise the approach to accomodate new users. Staffs at higher headquarters are not well suited to make real time decisions on employment of capability -- whether the OPNAV staff for FLTSATCOM or the Joint Staff under the provisions of MOP 178. In the absence of exercises, peacetime users will find it difficult to adapt to loss of service. With no clear guidelines, the crisis user will turn to some alternative source of SATCOM capacity, or some other communications media. While that may be effective in keeping unplanned users off a system, it probably will not result in the best response to the crisis.

The heart of the dilemma facing the FLTSATCOM OM, and the FLTCINCs, is that the satellite is extremely well suited for crisis support. The nine 25 khz UHF channels have more power and greater bandwidth than the NB AFSATCOM channels on the same spacecraft, and can repeat most digital modulation schemes (PSK, FSK, etc.) and data rates up to 9600 baud, plus FM voice. Only the wideband channel in the AFSATCOM system has comparable power and flexibility. As the population of deployable terminals increases the demand for support which can only be provided by FLTSATCOM will increase. At present it would be very difficult for the JCS or its agent to determine the impact of preempting existing FLTSATCOM service to accomodate a new user. In a real crisis, the JCS may have to act, even without this knowledge.

<u>DSCS</u>

The DSCS is the only joint-managed system, and has been operating for more than 15 years. Under MOP-178 the JCS retains responsibility for all aspects of the system, but delegates authority for many of the day-to-day functions to the Defense Communications Agency. In

most respects, DCA serves as both Executive Agent and Operational Manager for the system. DCA exercises control through an operations center in the Washington area and area centers in Europe and the Pacific theater.

Contingency operations have been a part of the DSCS charter since the earliest days. Terminals have been maintained on short notice call-up for deployment worldwide. The prime purpose of the contingency terminals is Defense Communications System (DCS) extension --providing temporary long-haul communications to an area without good service or to replace service lost through accident or damage. The terminals are large and expensive, much different from the UHF terminals used with AFSATCOM and FLTSATCOM. Even the latest generation AN/TSC-86 terminals take a combination of trucks and trailers to carry the equipment.

The fundamental difference in approach to crisis deployments between DSCS and the Service-managed systems is also reflected in the JCS approval process. For service-managed systems MOP-178 provides the means for approval of deployments and SATCOM system support. In effect, the movement of the terminal is controlled by the Service. For DSCS the movement of the terminals is controlled by another JCS policy document: JCS MOP-167, "Mobile/Transportable Communications Assets Controlled by the Joint Chiefs of Staff". If the contingency terminal can be accomodated within existing capacity, the JCS need only address the terminal deployment, while DCA assigns capacity for the new user.

The expense of the terminals and the fact that the DSCS system provided some crisis-response capability with organic resources has limited the introduction of service-managed DSCS contingency equipment. However, now that the Army, Air Force and Marines have acquired GMF terminals which operate through DSCS and which can be deployed by the Service in to provide non-DCS communications in crisis, the DSCS system has also begun to plan for support of this new class of users.

The operational concept for DSCS is based on assigning similar types of terminals to specific channels on each satellite. Clustering of users based on the characteristics of their communications allows for easier balancing of requirements. As a result, several tactical communities, those which use small (usually eight foot diameter antenna) terminals, are assigned to the same channel. Contingency terminals, GMF, White House Communications Agency and other tactical systems are all to be supported by one satellite transponder operating through a multi-beam antenna.

The system managers in DCA have recognized that their system is a likely target for jamming, and that the response to jamming is not much different from handling additional users. The jammer "robs" power and usable bandwidth from the approved users, just as assigning new users to the system decreases the power and bandwidth available for those already on the satellite. As a result, they have prioritized the communications using DCS restoration priorities and MOP-178. In addition, the system suffered several premature satellite failures in the early 1970s, and the OM had unfortunate experience in dealing with allocation of users following a loss of capacity.

Under the conditions that exist today, DSCS is prepared to handle most foreseeable crises. This is based on their planning and experience, but even more on the limited population of terminals. The problem for DSCS will come as the present generation of GMF terminals comes off the production line and is made available to Service contingency support units. The terminals will provide from 12 to 96 channels of 32 kbps or 48 kbps, which can carry data or voice. Obviously, the quality of the communications is exceptional. They will be an attractive addition to the communications package of any joint task force (JTF) or other deployed force. Under the operational concepts for the GMF, the number of terminals used to support a JTF could be substantial. One for each component headquarters, one at each Tactical Air Control System site, one at each major Army unit, etc. A deployment like that, especially in a jammed situation, would strain the capability of the DSCS OM.

Because the DSCS is under the control of the JCS, in theory the JCS itself will be responsible for making all the SATCOM approvals which force a reallocation of capacity (within some limits, DCA has authority to manage up to the point when an approved user must be denied service). The Organization of the JCS lacks the expertise to perform this task in real time, and they will certainly look to DCA for technical assistance. The complexity of satellite system management is such that technical issues cannot be divorced from the operational implications. Whether DCA is the proper organization to be advising on crisis or wartime priorities and allocations is a question that each CINC must consider.

Joint Control

The intent of MOP-178 is that the JCS will be the final authority in the control of MILSATCOM systems. In the days when the MOP was first drafted there were few assets and few users. Now there are over a thousand military terminals and a dozen or more active satellites. The problem is beyond the scope of a staff which looks at space operations as one of several important tasks. In order to properly advise, and at times direct the OM, it is essential the JCS be supported by a group which understands all aspects of the problem: the needs of the warfighters, the capabilities and limitations of MILSATCOM systems, the status of other space systems, the nature of the threat and other operational considerations.

Space Defense Operations Center

The Space Defense Operations center was established in 1979 to provide exactly the kind of fusion center described above. Since that time it has been developing ties to the OM of all military space system, SATCOM and others. Its purpose has been to collect status and make information readily available to the JCS, CINCs and the space system Operational Managers. While that process is far from complete, SPADOC has come along way toward bringing diverse communities together.

The charter which directed SPADOC isn't clear how far that Center should go toward exercising control over space systems. The decision was made at ADCOM that it was neither appropriate nor necessary for SPADOC to exercise day-to-day control over any space system. SPADOC will never have the expertise necessary to perform the functions of an Operational Manager. However, the time is approaching when the JCS will have to address how they will perform the functions retained by them for space operations, and whether they should delegate some of those functions to a joint CINC.

At present the joint command to perform these kinds of functions does not exist. They would be beyond the scope of the Aerospace Defense Command (ADCOM), even though SPADOC is one of its operating centers. For the JCS to delegate responsibility for space support to a Unified or Specified Command it will be necessary either to form another command or substantially change the role of an existing command. For the purpose of this discussion, it will be assumed that a joint Space Command has been established with the specific task of assisting the other U&S commands by exercising JCS authority over Service and Joint-managed space systems in times of crisis or national emergency. The SPADOC will be under the operational control of the commander in chief of that command (CINCSPACE). While the SPADOC would have no authority of its own, the CINC would use the Center and crew as his representative in situations which do not require his personal participation.

The SPADOC has or is acquiring all the necessary physical attributes to perform as the central coordinating point for management of MILSATCOM systems. The Operational Managers for the systems would retain responsibility for day-to-day management, and for implementation of JCS direction. SPADOC would pass this direction and monitor status through existing dedicated, secure communications circuits. Requirements from the operating commands would be passed to OM under current procedures, and SPADOC would be advised in those cases where system capability may be impacted or more than one operating force may be involved. Existing secure record and voice communications between SPADOC and the command centers for other U&S commands would be used. In addition to the Center itself, SPACECOM would bring experience in several related space operations missions.

Satellite Surveillance

Air Force Space Command, which exists today, has the task of detecting, tracking and cataloging all man-made objects in earth orbit. That includes approximately 4,800 objects, and requires over 30,000 radar and optical observations each day to keep the catalog current. The resulting data base is an essential ingredient in planning for future satellite positioning, since it includes inactive payloads and other debris as well as active satellites which would be carried in frequency management records.

The network also can assist launch agencies by tracking the boost vehicles and payload during all phases of orbital insertion. While this may duplicate the tracking information available from telemetry in a nominal launch, it can be invaluable in failure analysis when telemetry is lost. Further, in many cases the resolution of the systems is adequate to allow an assessment of the external shape of the

satellite on orbit.

Satellite Protection

SPACECOM is responsible for the protection of US space systems from hostile and natural threats. The same surveillance data which generates the catalog is used to predict possible collisions in orbit. With the increased density of satellites and launch debris in synchronous orbit, collision avoidance and position management will become essential to the overall effectiveness of MILSATCOM systems.

The capability for actual protection against hostile threat is limited, but growing. As military satellites are deployed with hardening, countermeasure systems and maneuver capability, the need for timely warning of threat and for coordination of responses will increase. It is not enough for the OM of a system to detect a threat and take appropriate actions to protect his system. The implications of the defense in terms of decreased capability must be assessed with clear knowledge of the operational missions which may be impacted. In many cases the OM neither knows nor needs to know this information, but it must be considered in planning defensive actions. The SPADOC will have the user's assessment of the value of each system and component in its data base, and can include these factors in advice to the OM and the JCS.

Negation

National and DOD space policies direct, within such limits imposed by international law, the continued development of an operational anti-satellite capability to deter threats to friendly space systems, and preserve our right of self-defense. If it is deployed, CINCAD will exercise operational control over the ASAT from the SPADOC and the Mission Control Center in Cheyenne Mountain.

JOINT OPERATIONS

The real value of MILSATCOM coordination through SPADOC is not so much a matter of changing the way we would apply existing assets as changing the way we think about space operations. The problems that would arise in responding to a crisis come from years of thinking of systems as resources to be used to satisfy the needs of a small community of users. A Space Command would provide the vehicle to focus on joint planning, joint operations, and timely allocation of capability to meet the needs of combat forces.

The role of a joint Space Command would begin at the earliest part of the acquisition process. CINCSPACE would provide a focal point for the unified and specified CINCs to inject requirements into the planning process, and a voice in the Planning, Programming and Budgeting System. The involvement would continue throughout the acquisition as the command assisted the executive agent in balancing technical considerations with such operational factors as survivability enhancements, replenishment philosophy, position management and operational concepts. Finally, exercises in joint operations would be coordinated through the SPADOC.

This final action, coordination of joint exercises, is one area where SPADOC and OM of MILSATCOM systems can and should begin to work together now. The experience with space systems in exercises is limited, and noted most for pointing out areas where improvement is needed. Although no OM likes to think about intentionally denying service, and no user wants to see his support disrupted, it is essential that operators practice how they would respond to increased demands or loss of capability --even to the extent of moving users from one system to another. The key to a good crisis response is knowing beforehand what must be done and how to do it. The knowledge can only come through good planning followed by test and exercise.

In order for SPADOC to take on a role in MILSATCOM coordination two things must occur. First, the SPADOC must have people who understand the operational missions of the warfighters and the capabilities of the SATCOM systems. Services must be willing to assign good people to staff and crew positions in Space Command. Second, the SPACECOM staff and the Operational Managers must work very closely to define the proper division of responsibility. It would be very easy for SPADOC to take on a job it could not perform. The OM are the experts in the systems and can best determine how SPADOC can assist them in performing their missions.

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COMMAND POST MODEM/PROCESSOR (CPM/P)

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ABSTRACT

The Command Post Modem/Processor (CPM/P) Advanced Development Program makes extensive use of micro-computer technology in the design of a subsystem of an Airborne Satellite Communications (SATCOM) system. This SATCOM system is being designed for eventual application on the Airborne Command Post fleet of aircraft to provide command of functions including message handling (routing), satellite command and control, satellite ranging and pointing computations, and complex signal processing while achieving a significant reduction in size, weight, power consumption, and volume as compared to present technologies. In addition, maintainability, reliability, life-cycle cost, and self-test are significant objectives in the development effort. The three principal units of the CPM/P are the Red Processor, the Black Processor, and the Modem, each housed in 1/2-ATR long LRU and each containing two micro-computers. The CPM/P and the associated receiver/transmitters are controlled through the use of a plasma display, an interactive display which is designed to aid the operator in decision making and thus reduce demands on the operator during system operation.

Introduction

The Command Post Modem/Processor (CPM/P) Advanced Development Program was initiated by the Avionics Laboratory of the Air Force Wright Aeronautical Laboratories in March 1978 under Contract F33615-77-C-1269 with the Linkabit Corporation of San Diego, California. The general program objective was the development of Military Satellite Communications (MILSATCOM) technologies in support of Airborne Command Post terminal segment development for existing and planned satellite communications systems. The CPM/P is the modem/processor subsystem of a comprehensive Satellite Communications (SATCOM) terminal. The CPM/P is designed to interface with associated UHF/SHF/EHF Receiver/Transmitter (R/T) terminal subsystems and other onboard equipments to provide the integration function within the SATCOM terminal. Through the use of micro-computer technology and extensive digital implementation, the CPM/P provides a multiplicity of communications, command, and control capabilities while achieving a significant reduction in size, weight and power consumption as compared to existing technological capabilities. Operating as a part of the SATCOM terminal the CPM/P provides for emergency action message (EAM) dissemination and communications among the National Command Authorities, the Joint Chiefs of Staff, the Commanders-in-Chief, and the strategic force elements consisting primarily of bombers and missle launch control centers. The CPM/P design includes the capability to configure/control/monitor the SATCOM terminal R/T subsystems; to initiate command functions for satellite control; and to establish and control communications networks. The SATCOM terminal, including the CPM/P, is designed to operate with a variety of satellites in geosynchronous and inclined orbits and in the UHF, SHF, and EHF frequency spectrums.

The SATCOM terminal is comprised of a variety of equipments from a variety of sources. The UHF R/T group equipments and some of the Input/Output (I/O) group equipments are presently in use in a UHF SATCOM terminal on the Airborne Command Post to Provide UHF AFSATCOM I Satellite Communications. The SHF/EHF capability within the terminal is provided by the Small EHF/SHF Airborne SATCOM Terminal (SESAST)[1]. The SESAST was developed under a parallel advanced development program within the Avionics Laboratory. A feature of the SESAST design provides for either autonomous operation or integrated operation with the CPM/P. When operating with the CPM/P total control of terminal operation is achieved through that CPM/P including SESAST initialization, configuration, and monitor.

CPM/P General Description

The principal components of the CPM/P development effort are the Modem, the Black Processor, and the Red Processor. Two Modems along with the Black and Red Processors make up the CPM/P. These four units are shown in Figure 1. Each unit is packaged in a 1/2 ATR-Long chassis. Figure 2 is a diagram of the SATCOM Terminal with photographs of the major CPM/P components. The primary function of the Modem, called the Command Post Modem (CPM), is to transform baseband digital information into the appropriate uplink I-F waveform structure and, conversely, to transform received downlink I-F waveforms to baseband for further processing within the CPM/P. The Black Processor controls the routing of data between the Red Processor and the CPMs, controls the UHF Radio subgroup, and computes satellite range/range rate and antenna pointing information. The Red Processor provides

the system control functions and the interface with the I/O group.

Three other smaller units, the R/T Interface, the Reference Distribution, and the Relay Control, were developed as a part of the CPM/P and perform interface functions. The functions currently performed in these smaller units would probably be integrated into the major Line Replaceable Units (LRUs) in the next stage of development.

Maintainability, reliability and life-cycle cost were considerations in the CPM/P development effort. To this end the CPM/P is designed with numerous common modules, including one power supply which is common to the three major LRUs. The chassis for the Red Processor and the Black Processor are also interchangeable. Significant reductions in size, weight, and power consumption also contribute to improved reliability, maintainability, and life-cycle cost. The CPM/P also includes a limited built-in-test capability.

CPM/P Architecture

The primary development objective of the CPM/P program of substantially reducing physical size (volume), weight, and power consumption while increasing functional capability, were achieved through the use of state-of-the-art micro-computer technology and the use of extensive digital implementation. The basis of the CPM/P architecture was a result of the works of Gilhousen[2] and Jacobs[3]. The micro-computer described by Gilhousen and Jacobs was designed for use in the processing of complex signal waveforms, sometimes called the Linkabit Microprocessor or LMP.

A block diagram of the LMP is shown in Figure 3. This block diagram of the LMP architecture is from a software point-of-view. The major characteristics of the LMP are as follows:

- -- The average instruction execution rate of the LMP is 3 million instructions per second;
- -- The LMP is composed of standard integrated circuits;
- -- Its instruction set consists of 29 instructions;
- -- The LMP does not include interrupt capability but relies on testing of external flags; and
- -- It contains a hardware monitor for overflow/underflow and illegal operation codes or code boundaries.

Within the CPM/P the hardware implementation of the LMP is partitioned into either a three or four card set consisting of a Processor Arithmetic Card, a Processor Control Card, and either one or two Processor Memory Cards. Each major LRU contains two LMPs. The card layout for the Command Post Modem is shown in Figure 4. The Processor Arithmetic Cards (A12) are interchangeable as are the Processor Control Cards (A13). The program is stored in ROM on the Processor Memory Cards. The LMP can address up to 64 pages of ROM, with a page consisting of 4096 instructions and each instruction 5 bits in length. Each Processor Memory Card can contain up to 15 pages of ROM or a total of 30 pages per LMP using 16K ROM devices. The Processor Memory Cards are designed to accommodate 32K ROMs which will allow expansion to 60 pages per LMP. Using the 16K ROMs the CPM/P is presently at approximately 84% of capacity.

SATCOM Terminal

The function of the CPM/P is best illustrated when described as an operating part of the multi-functional airborne SATCOM terminal shown in Figure 2. A number of advanced development technologies provided in this terminal can be transitioned to the operational fleet to meet the Airborne Command Post requirements for existing and planned MILSATCOM systems.

The Input/Output (I/O) group consists of two plasma displays, two Automatic Send-Receive (ASR) devices, a high speed printer, and a magnetic tape cassette unit. The two plasma displays provide for centralized control of terminal operations and configurations, with the ASRs supplying backup. The operation of the plasma displays are complementary, i.e. the two units would not be used on the same job at the same time. The high speed printer is used to log all communications traffic and selected status/control information. The function of the cassette unit is to load the system data base and satellite ephemeris data.

The Red Processor provides the interface with the I/O group and stores the operating data base. The Black Processor serves as the interface with the Modems and computes satellite range/range rate and pointing information. The function of the Inertial Navigation System (LTN-51) is to furnish aircraft dynamic data required in the computation of satellite range/range rate and pointing information. The EAM Alarm provides an audible and visual indication of the reception of an Emergency Action Message.

The two Modems are identical and perform all the signal processing functions. They can provide simultaneous communications through different satellite links and/or provide redundancy to improve reliability. The KI-35s shown interfacing with the Modems supply TRANSEC compatibility with the SCT satellite communications links. The Modems interface with the UHF R/Ts and the SESAST at an intermediate-frequency of 70 MHz through the RF switching matrix. The UHF R/Ts are full-duplex AN/ARC-171s presently used in the operational AFSAT I Command Post terminals. The SESAST provides the SHF/EHF capability.

A detailed block diagram of the SATCOM terminal is shown in Figure 5. The blocks accentuated by the heavy borders are the equipments developed or purchased as a part of the CPM/P development effort.

Multiple Satellite Operation

The SATCOM terminal is designed for multiple satellite operations with a data base of up to forty satellites with a variety of circular and elliptical orbits. The terminal can operate simultaneously with either two UHF satellites or one UHF and one SHF/EHF satellite. The design provides for pre-correction in time and frequency for the uplink signals radiated by the aircraft. This pre-correction compensates for relative Doppler and the time delay between the aircraft and the satellite. In addition, azimuth and elevation pointing information is computed within the CPM/P to point the EHF/SHF directional antenna. This pre-correction in time and frequency along with the antenna pointing information allows for rapid acquisition of complex waveforms, as well as "open-loop" operations with satellites which have no continuous communications or telemetry downlinks.

To achieve efficient and accurate operation with a forty satellite data base while minimizing downtime during switching between satellites, a comprehensive ephemeris computational algorithm to compute range/range rate and antenna pointing angles was developed and implemented in the CPM/P. The initial analysis and development of the ephemeris computational algorithm was accomplished by Orincon[4]. The Orincon effort was followed by implementation in the CPM/P described by Rothmuller and Rosenlof[5].

Centralized Control

Due to the number and variety of communications assets which make-up and interface with the SATCOM terminal, the control/monitor function is an important design consideration. The primary display/control function in the CPM/P and the SATCOM terminal is achieved through the use of a plasma display. The display/control function is designed to require minimal operator interaction and serves as an aid to the operator in decision making.

The method of display/control is achieved by providing a menu of choices to the operator through the use of the plasma display. Following a selection, another menu of choices is offered, and so on, until the system is operating with a given set of conditions. Terminal resources are automatically allocated and system operating parameters/levels are automatically set through the process. A typical menu set is shown in Figure 6. The upper section of the screen displays status messages which are provided automatically, ranging from system faults to the availability of terminal assets. Each message is preceded by the time and date with the most current message on the bottom. Only the four most recent messages are displayed. Status messages are also routed to the high speed printer for permanent logging. The lower section of the screen displays the menu of choices. Graphics are also used to aid the operator.

The centralized control concept and the design of the CPM/P provides a limited implementation of Built-In-Test (BIT). Detected system faults are automatically displayed as status messages (upper section of the plasma display) including the possible location of the fault. The basis for the CPM/P BIT is a result of the BIT program implemented in the UHF Dual Modem[6].

Summary of CPM/P Principal Features

The principal features of the CPM/P when operating as a part of the SATCOM terminal as described in this paper can be summarized as follows:

- Significant reduction in size, weight, and power consumption with increased functional capability;
- Compatible with all communication modes of both the AFSAT I and the Single Channel Transponder (SCT) Satellite Communications Systems;
- Satellite Command/Control and Monitor Capabilities;
- Centralized Control over the SATCOM terminal;
- Multiple satellite operation with a forty satellite data base, and range/range rate and antenna pointing computations; and
- A number of advanced development technologies which can be transitioned to the next stage of development.

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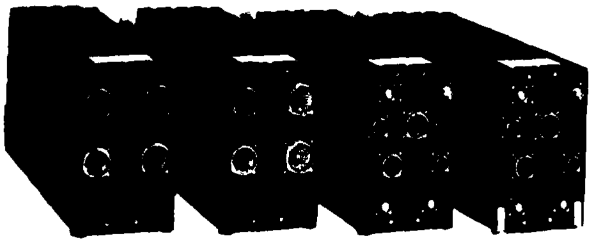


CPM/P PRIMARY LRU's
Figure 1

COMMAND POST MODEM / PROCESSOR

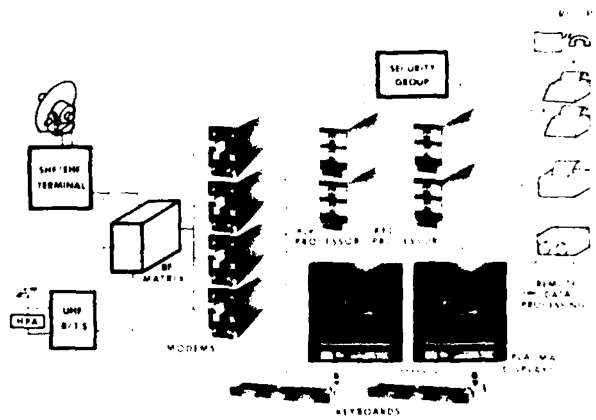


Figure 2

LMP ARCHITECTURE
(FROM A SOFTWARE POINT-OF-VIEW)

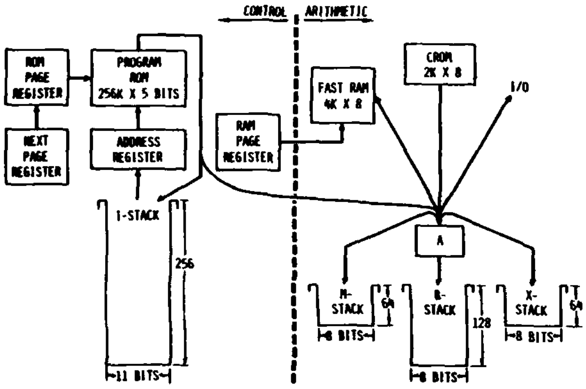
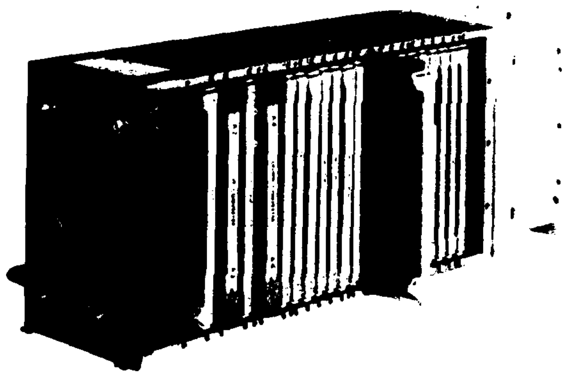
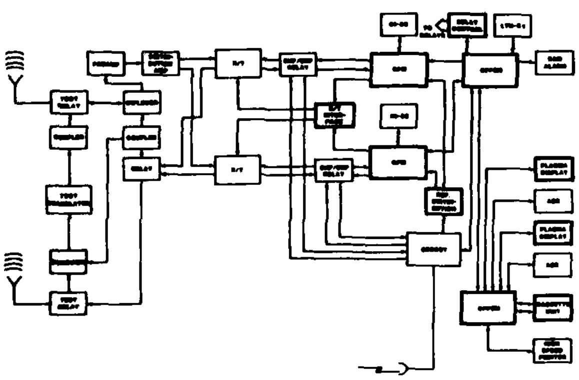


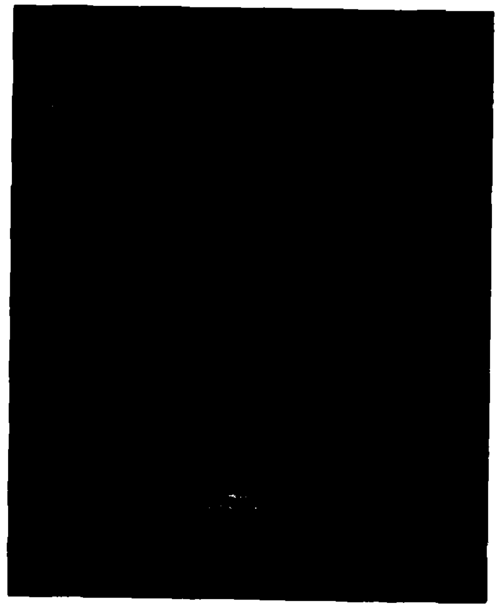
Figure 3



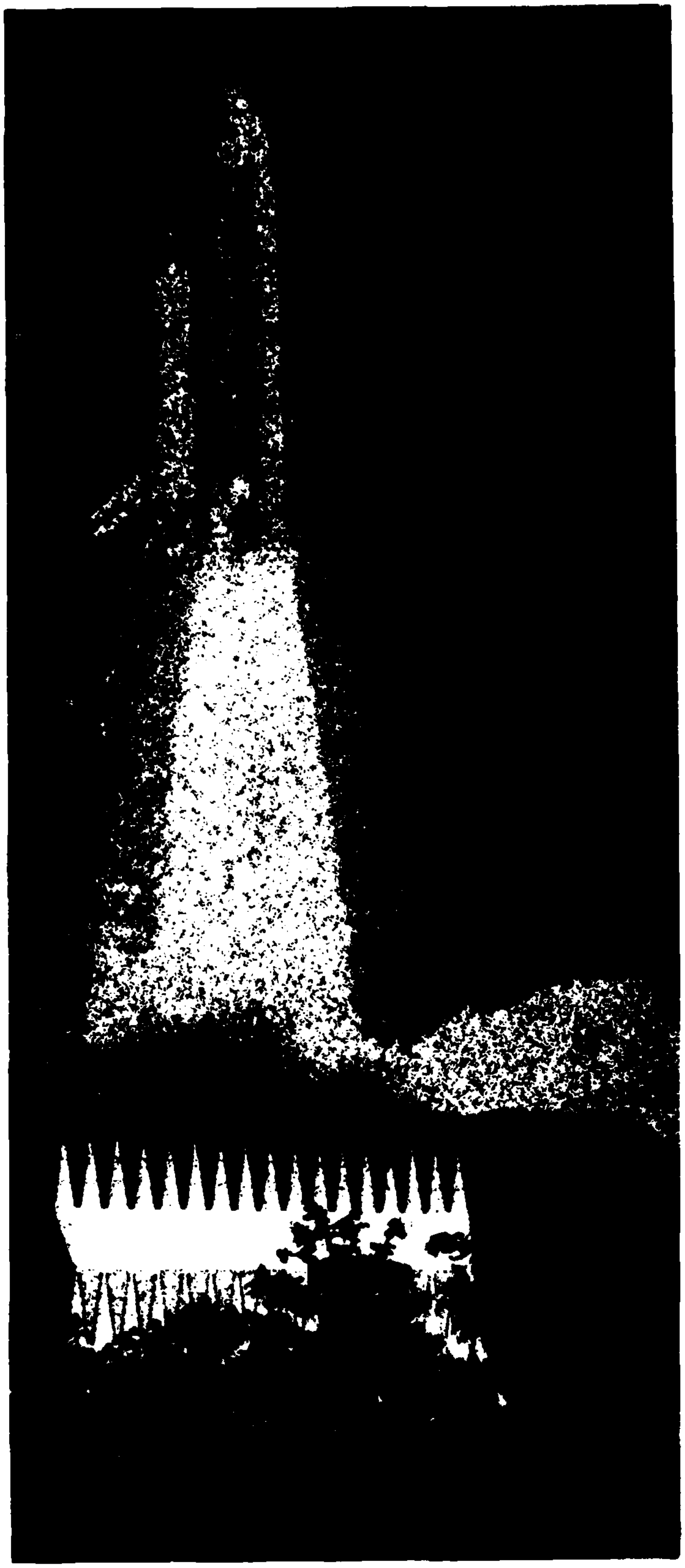
COMMAND POST MODEM
Figure 4



SATCOM TERMINAL BLOCK DIAGRAM
Figure 5



SAMPLE MENU
Figure 6



Session 5

DOD Command and Control Centers

Session Chairman: R. Laskin, *Ford Aero and Comm Corp.*

The Papers

Invited Paper—Mission Operations Impact of Specific Shuttle Vehicle Improvements

Invited Paper—Interoperability of Space Communications Systems

Invited Paper—A Commonality Approach to DOD Command and Control Centers

Invited Paper—CSOC: Beginning an Era of Air Force Space Operations

CSOC: Evolution to Military Space System Control

The CSOC Communications Acquisition

AD P002152

MISSION OPERATIONS IMPACT OF SPECIFIC SHUTTLE VEHICLE IMPROVEMENTS

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ABSTRACT

This paper highlights a study activity which assessed the impact of proposed Shuttle vehicle improvements on the tasks associated with Shuttle Mission Operations. These tasks were divided into the following Mission Operations phases: (1) Flight Planning Phase; (2) Flight Readiness Phase; (3) Flight Control Phase. Vehicle improvements identified for assessment were: (1) Autonomous navigation; (2) Automated failure diagnosis; (3) Increased crew size; (4) Onboard consumable analysis; (5) Software Flight Data File; (6) Advanced inflight maintenance. Task analyses of the Mission Operations phases provided the baseline criteria on which to make the impact assessment of the improvement candidates. Incorporation of vehicle improvements which contribute to autonomous Shuttle operations is one of the proposed solutions for reducing Mission Operation activities and staffing.

INTRODUCTION

As the Shuttle Transportation System (STS) advances into the operational era all Mission Operations activities should be examined with the intent of providing payload and scheduling flexibility, supporting increasing flight rates, and reducing cost per flight. One area which is a major contributor to current STS cost is Mission Operations. Mission Operations in the context of this study are those activities which must be performed during the Flight Planning Phase of a mission, those activities performed during the Flight Readiness Phase of a mission, and those activities performed during the Flight Control Phase of a mission. Launch operations and vehicle turnaround activities were considered a separate subject and were not directly addressed in this study.

Mission Operations (By Phase)

Flight Planning Phase

- o Flight Integration
- o Fight Design (System X and System Y)
- o Crew Activity Planning (CAPS)

Flight Readiness Phase

- o Training and Simulation
- o Flight Software Preparation
- o Ground Systems (MCC H/W & S/W)

Flight Control Phase

- o Procedures Development
- o Flight Operations Support Personnel (FOSP)
- o Flight Crews

Numerous Shuttle vehicle improvements have been proposed and evaluated on the basis of performance, safety, turnaround time reduction, and cost. One area which has been identified as having the potential of reducing Mission Operations, is the implementation of vehicle improvements with autonomous vehicle thrust. It was the intent of this study to evaluate selected autonomous vehicle improvement candidates for impact in the Mission Operations area of Flight Planning, Flight Readiness and Flight Control.

It was anticipated that the impact of the vehicle improvement candidates will reduce Mission Operations in many respects. However, it was also anticipated that there would be displacements of activities as well as increases in activities associated with improvement candidate implementation. This aspect of proposed improvements has seldom been addressed in the traditional evaluation studies performed for NASA programs.

APPROACH

The basic approach used for this study is illustrated in Figure 1. The initial investigation focused on identifying vehicle improvement candidates which provide or contribute to autonomous vehicle operations. Reviews of existing studies and related documentation were performed and a group of potential candidates were identified. From this preliminary group, the most influential six candidate improvements were selected and des-

cribed for subsequent utilization in this study.

The next step in the study approach was the development of task analyses for the respective Mission Operations activities. Each of the Mission Operations phases (Flight Planning, Flight Readiness, and Flight Control) was further divided into the specific areas of support and the tasks within each support activity were identified.

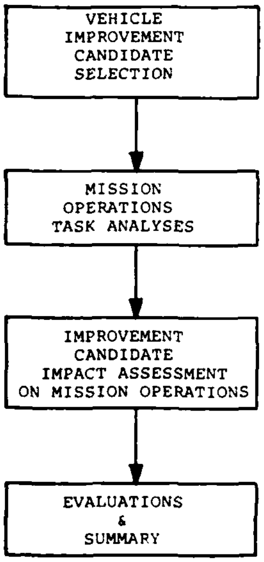

FIGURE 1 - STUDY APPROACH

The third step in the study approach called for the impact assessment of the candidate vehicle improvements upon the individual Mission Operations task analyses. By utilizing the candidate vehicle improvement descriptions and identified capabilities, the impact on the Mission Operations task analyses were identified.

The assessment data was subsequently utilized to compile the overall impact evaluation and summary.

Improvement Candidate Descriptions

The following paragraphs provide a summary description of the autonomous vehicle improvement candidates.

Autonomous Navigation - Autonomous Navigation in the conceptual form being studied in the literature utilizes an Orbiter onboard navigator in conjunction with the Global Positioning System (GPS) to obtain independent Orbiter navigation updates (3). This concept negates the requirement for externally generated updates to the navigator from dedicated tracking and data processing facilities on the ground.

Automated Failure Diagnosis - Automated Failure Diagnosis capability for the Orbiter will be implemented as applications to the onboard software program. Upon activation by an out-of-tolerance condition the program would cycle to diagnose the problem. Upon completion of the diagnosis, the failure solution will appear on the onboard CRT along with appropriate corrective action instructions to the crew. The automated failure diagnosis applications will apply primarily to non-software driven systems.

Increased Crew Size - An increase in size to four or more members will occur on operational Shuttle flights. This will allow the Orbiter to be operated on a "shift" basis which permits continuous flight activities. The crew will be available for full time monitoring of the Orbiter and for the performance of off-nominal procedures if required. The Spacelab mission will provide the initial occurence of "shift" operations onboard the Shuttle.

Onboard Consumable Analysis - Onboard consumable analysis is also a flight software program application. This program will give the flight crew the capability to evaluate all onboard consumables and provide projections of supply for various vehicle conditions. The crew would have the capability to evaluate contingency deorbit cases independent of ground tracking and data processing facilities.

Software Flight Data File - Placing certain volumes of the Flight Data File in the mass memory of the onboard software load will result in a weight reduction for the Orbiter. This concept would apply to flight documents that are utilized during the on-orbit phase of the mission. This concept would also provide a hard-copy capability on the Orbiter to reduce CRT display burden.

Advanced Inflight Maintenance - Advanced Inflight Maintenance (IFM) will increase the probability of mission success by providing the Orbiter crew with the capability to effect onboard repairs. In the advanced concept these repairs are envisioned to be accomplished on payloads (Orbiter IFM will be standard practice). Equipment, spare parts, and procedures would be stowed onboard the Orbiter as an "optional service". The planning and training for this capability would also be provided as part of the "optional service". Payloads having national priority or pay-

loads representing new technology and unproven reliability would be candidates for the advanced inflight maintenance service.

MISSION OPERATIONS TASK ANALYSIS DEVELOPMENT

The development of the Mission Operations task analyses was accomplished by utilization of NASA JSC documentation, NASA interviews with incumbent NASA JSC and contractor personnel (6), (7), (8). The tasks identified are presented in Tables 1, 2 and 3 for Flight Planning, Flight Readiness, and Flight Control activities respectively.

IMPROVEMENT CANDIDATE IMPACT ASSESSMENT

During this phase of the study task each of the candidate improvements was evaluated for impact to the Mission Operations phase and functional activities. The evaluation first addressed whether or not there was impact to the functional

FLIGHT INTEGRATION	FLIGHT DESIGN	CREW ACTIVITY PLANNING
• Perform Payload Requirements Analyses • Develop Flight Phase Expertise • Develop Conceptual Flight Profiles (CFP) • Perform Data Base Mgmt. • Perform Flight Phase Integration • Perform Flight Plan Development • Perform Payload Integration Plan (PIP) Analyses • Perform Compatibility Analyses • Develop Payload Integration Requirements • Perform Rendezvous/Proximity Operations Integration • Prepare Operational Flight Plans • Perform Mission Standardization Analyses • Identify Mission Constraints & Limitations	• Design Trajectory/Mission Profiles • Perform Consummable Analyses • Perform Navigation Analyses • Perform Attitude Analyses • Utilize System X • Utilize System Y • Develop Detail Timelines • Develop Detail Flight Plan Inputs • Perform Mass Properties Integration • Develop Abort Profiles • Perform Flight Design Assessment • Prepare Simulator Data Packs • Develop Planning Tool Improvements	• Develop Flight Techniques Expertise • Serve as Flight Activities Officer (FAO) • Develop Crew Activity Timelines • Develop Attitude/Pointing Requirements • Prepare Crew Activity Plans • Integrate Flight Documentation (FDF) • Perform Interface Functions • Perform Flight Manifest Integration • Develop Crew Activity Planning System (CAPS) Improvements • Perform Realtime Replanning Functions

TABLE 1 - FLIGHT PLANNING TASK ANALYSIS

TRAINING AND SIMULATION	FLIGHT SOFTWARE	(MCC H/W, S/W)
• Perform Training Requirements Analyses • Develop Training Plans and Annexes • Develop Training Flows • Develop Certification Criteria • Develop Training Scripts • Perform Script Checkout • Maintain/Update Training Records • Develop Simulation Requirements • Prepare Reset Point Data and Switch Lists • Develop Simulator Comm. Configuration Requirements • Prepare Simulator TM Data Packs • Perform Phase Training • Perform Integrated Sims. • Perform Simulator Validation Tests • Prepare Post Training Reports • Schedule Training (Resources and Facilities) • Support Payload Training Requirements	• Process and Utilize S/W Input Products • Code S/W Updates • Perform S/W Segment Verification • Perform S/W Tape Builds • Produce Mass Memory Load Units • Perform Mass Memory Verification • Perform H/W, S/W Integration • Develop S/W Load Patches • Maintain S/W Configuration Data • Maintain S/W Schedule & Status Data • Perform Data Base Updates • Prepare S/W Users Guide	• Perform Comm. Interface Sys (CIS) updates • Perform Data Computation Complex (DCC) Updates • Perform Control & Display System Updates • Perform Ground S/W Integration, Verification • Perform Ground System Interface Verification • Provide External Comm. Verification • Provide Mission Support • Perform Payload Updates to POCC • Perform Console Updates • Perform Develop Ground System Enhancements • Perform Configuration Mgmt. • Provide Schedule & Status Information

TABLE 2 - FLIGHT READINESS TASK ANALYSIS

PROCEDURES	FLIGHT OPS SUPPORT PERSONNEL (FOSP)	FLIGHT CREW
• Prepare Checklists • Prepare Handbooks • Perform Flight Data File(FDF) Verification • Support Flight Technique Mtgs • Prepare Cue Cards • Prepare Charts/Tech. Aids • Maintain FDF Change Control • Support Payload Documentation Requirements • Develop Stowage Lists • Standardize Procedures • Develop Mission Control Center Procedures	• Develop MCC Requirements • Perform Procedure Verification • Support Ground System Verification • Achieve Position Certification • Provide Real Time Mission Support • Support Launch Site Testing • Perform Post Flight Analyses • Develop Handbooks • Support Crew Interface Tests • Develop Mission Rules • Develop Downlist Formats • Prepare Orbiter Command Data • Prepare Payload Command Data • Develop PIP Annexes • Support Flight Tech. Mtgs. • Support Mission Rule Mtgs.	• Perform Mission DTO's & PIP Requirements • Support Flight Tech. Mtgs. • Support Mission Rule Mtgs. • Achieve Position Certification • Support Verification Activities • Support Launch Site Testing • Support Post Flight Activities

TABLE 3 - FLIGHT CONTROL TASK ANALYSIS

activities as identified in the specific task analysis. When an impact condition was identified an assessment was made to determine if the condition was encountered on the initial mission only or would cause recurring impact on all subsequent missions. The final determination to be made dealt with the workload influence of the impact. Factors were evaluated to identify a positive (+) or negative (-) workload index for each impact condition. In certain instances impacts were identified but the workload index remained undetermined because the workload increase and decrease caused by the improvement would approximately cancel out.

IMPROVEMENT IMPACT SUMMARY MATRIX

Table 4 reflects the Improvement Impact Summary Matrix. This table indicates that providing the flight crew with autonomous vehicle capabilities will cause workload increases in most of the Mission Operations categories. The most significant workload increase is on the

Work Load Index (±)	MISSION OPERATIONS								
	FLIGHT PLANNING			FLIGHT READINESS			FLIGHT CONTROL		
CANDIDATE ENHANCEMENTS	FLT INTEG.	SYS X&Y	CAPS	TRAINING & SIMULATION	FLIGHT SOFTWARE	MCC H/W, S/W	PROC.	FOSP	CREW
Autonomous Navigation	--	✓(+)	✓(+)	✓✓(+)	✓(+)	✓(+)	✓(+)	✓(-)	✓✓(+)
Automated Failure Diagnosis	--	--	✓(-)	✓✓(-)	✓(+)	✓(+)	✓(+)	✓(-)	✓✓(-)
Increased Crew Size	✓(+)	✓(+)	✓(+)	✓✓(+)	--	--	✓(+)	✓(-)	✓(?)
On-Board Consumable Analysis	--	--	✓(+)	✓✓(+)	✓(+)	--	✓(+)	✓(-)	✓✓(+)
Software Flight Data File	--	--	✓(+)	✓(+)	✓(+)	--	✓(-)	✓(?)	✓(+)
Advanced In-Flight Maintenance	--	--	✓✓(+)	✓✓(+)	--	--	✓✓(+)	✓✓(-)	✓✓(+)
Net Work Load Impact	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)

✓ Initial Impact
✓✓ Recurring Impact Potential

TABLE 4 - IMPROVEMENT IMPACT SUMMARY MATRIX

flight crews expected. However, the increased workload in simulation and training appears equally substantial and may cause an increased need for training facilities and resources. The most significant reduction in workload will occur in the area of flight operations support. It was beyond the scope of this study to further develop the impact assessment in quantifiable terms (i.e., man hours). The natural progression for the study would be the development of a mathematical model in which the mission complexity (high, medium, low), the mission duration, and the crew size would be variables to be initialized for evaluation of a particular improvement candidate. This would then permit a summation of the impact across the mission phases and provide a quantified answer for staffing or cost estimate purposes. An additional parameter would be the estimate of pay-back potential of implementing a particular improvement candidate across a specific number of missions.

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COLONEL ROBERT H. GIBSON

Colonel Robert H. Gibson is the director of the Advanced Space Communications Program, Deputy for Space Communications, Air Force Space Division, Air Force Systems Command, Los Angeles Air Force Station, California.

Colonel Gibson was born in Quincy, Illinois. He was awarded a Bachelor of Science degree in General Engineering from the University of Illinois in 1961. He received a Master of Engineering degree in Industrial Engineering, specializing in Computer Science, from Texas A&M University in 1968.

Colonel Gibson entered the U.S. Air Force through the Reserve Officer Training Corps program at the University of Illinois. His initial assignment was the basic Communications-Electronics Officer Course at Keesler AFB, MS with subsequent assignment to Clinton-Sherman AFB, OK as a SAC Communications-Electronics Maintenance Officer. He spent three more years in SAC as Chief Computer Operations and Programming, 33rd Communications Squadron, March AFB, CA.

After completing graduate studies at Texas A&M University in May 1968, Colonel Gibson served as Base Communications Operations Officer, Tan Son Nhut AB, RVN. Upon returning to the States, Colonel Gibson attended the Staff Communications-Electronics Officer Courses at Keesler AFB, MS, and was then assigned to Washington, D.C. as Deputy Director of Teleprocessing, Air Force Data Systems Design Center. In January 71, he transferred to the White House Communications Agency (WHCA) where he managed the project to automate WHCA's Communications Center in the White House.

After completing Armed Forces Staff College, Norfolk, VA, in February 1974, Colonel Gibson spent 30 months as Chief of the Defense Communications Agency Field Office in Okinawa, Japan. From Okinawa he went to SAC Headquarters, Strategic Communications Area, Offutt AFB, NE, where he was Director, Airborne C3 development; Director, Communications Plans and Policy; and Director, Communications Readiness and Requirements.

Colonel Gibson completed Air War College, Maxwell AFB, AL, prior to being assigned to the Advanced Space Communications Program in July 1980.

His military decorations include the Bronze Star, the Meritorious Service Medal with one oak leaf cluster, the Joint Service Commendation Medal, and the Air Force Commendation Medal with one oak leaf cluster.

Colonel Gibson and his wife, the former Judy Ribick, have three sons: Tom, Tim, and Terry; and a daughter, Julie.

INTEROPERABILITY OF SPACE COMMUNICATIONS SYSTEMS

COL ROBERT H. GIBSON

AIR FORCE SYSTEMS COMMAND, LOS ANGELES, CALIFORNIA

We define interoperability as the ability of networks to interchange links, space nodes or ground nodes. This concept requires three ingredients for implementation. The first part is functional satellite and ground data link standards for mission data; communications; and tracking, telemetry and command (TT&C). All links use a common transmission format so diverse hardware from a variety of systems can interoperate. The second component is an architecture that defines the systems, links, and facilities (the nodes) which will be internetted. The last ingredient is the operations concept which provides the organization, procedures and protocols that allow interoperability.

This paper outlines and examines all three areas. It describes the problems and compromises required to produce a useful satellite data link standard and presents interoperability scenarios that illustrate alternate routes and how they can be used.

A COMMONALITY APPROACH TO DoD COMMAND AND CONTROL CENTERS

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ABSTRACT

For the past 25 years the Department of Defense (DoD) has become increasingly involved in the use of satellites for communications, navigation, surveillance and other missions. The support of these space missions required a growing number of ground systems which were developed essentially independent of each other. The advent of the Space Transportation System (STS) as a reusable launch vehicle and the upgrade of several existing command and control centers have provided the opportunity to pursue commonality in the development or upgrade of these centers. The potential commonality included software, hardware, procedures, training and operational concepts. Further investigation revealed excellent commonality in high level software and data processing systems. The advent of the Consolidated Space Operations Center (CSOC) which comprises seven segments and some co-located program elements provided even more impetus for a commonality approach to DoD command and control centers.

The programs specifically addressed included the Shuttle Operations and Planning Complex (SOPC), the Data System Modernization (DSM), the Global Positioning System (GPS) and the Johnson Space Center (a National Aeronautics and Space Aministration facility). The commonality results achieved to date and the ongoing investigation will be presented in the paper.

INTRODUCTION

The Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) utilization of the Space Transportation System (STS) and other satellites requires ground control centers. Each control center must provide certain capabilities and perform certain functions that are, to a large degree, common to the other control centers.

Several factors such as outdated equipment, increased data rates, saturated data systems, high life cycle costs and single nodes of failure prompted the upgrade or building of a number of control centers. Those under DoD include:

- The Air Force Satellite Control Facility (AFSCF) is the current DoD facility for controlling and monitoring military satellites. The Data System Modernization (DSM) is the upgrade to the command and control segment at the SCF and is in development.
- The NAVSTAR Operations Center houses the Master Control Station (MCS) for overall control of the Global Positioning System (GPS) and is currently under development.
- The Shuttle Operations and Planning Complex (SOPC) will be the DoD facility for planning and controlling military Shuttle missions.
- The Space Defense Operations Center (SPADOC) provides centralized communications and command for defense purposes.
- The Satellite Operations Complex (SOC) is a planned backup and loadsharing replication of DSM.
- The Consolidated Space Operations Center (CSOC) is scheduled to provide a centralized facility for military space operations. It will house SOPC, SOC, MCS and other military programs.
- Vandenberg Air Force Base (VAFB) provides launch facilities for the Western Test Range.

Mission Control Centers under NASA include:

- The Johnson Space Center (JSC) where NASA plans and controls civilian space missions and provides an early DoD Shuttle capability prior to SOPC activation.
- The Kennedy Space Center (KSC) provides Eastern Test Range launch facilities for NASA and DoD.
- The Goddard Space Flight Center (GSFC) which provides network control for NASA.

Thus, the situation exists whereby DoD and NASA are upgrading or planning to build several control centers which appear to have a large set of common requirements. The problem is to determine the best means of providing that common set of capabilities in a cost-effective and timely manner. Furthermore, the Zeiberg TWX[1], the Office of Management and Budget guidelines and Presidential Directive 37 imposed specific requirements and factors to be considered in implementing the DoD control centers. The more significant ones are as follows:

a. *Interoperability* – *the requirement for one center to perform* specified backup functions for another center;

b. Transition – the transitioning of flight operations from one center to another;

c. *Training – the addition of interoperability and transition to* the normal training requirements;

d. Transferability – the recovery or transfer of large amounts of existing software;

e. Technology – the upgrading of outdated equipment and the replacing of special built equipment with commercial gear while maintaining interoperability and software transferability; and

f. Configuration Management – the requirement to keep separate centers in some degree of synchronization to provide the ability to use common software products.

[1] The Zeiberg TWX was a request from Dr. Zeiberg, Deputy Undersecretary of Defense for Strategic and Space Systems, to Air Force Systems Command for support in investigating specified satellite related issues.

THE COMMONALITY APPROACH

In the past, centers have been developed essentially independently, not drawing upon each other's experience and products. Such action has resulted in some amount of risk, schedule and cost exposures that perhaps could have been avoided. However, recent studies within FSD have shown that it is highly desirable to develop these control centers so as to take advantage of common elements in both hardware and software from one center to another. In addition, it is desirable to use existing, field-proven components when possible. This commonality provides significant advantages in reducing development and life-cycle costs, improving schedules, and perhaps, most importantly, enhancing reliability and thus reducing the overall technical risk in developing highly complex realtime command and control systems (Refer to Figure 1.)

The commonality approach embraces hardware, software, training, procedures and other aspects of command and control centers. This paper focuses on a commonality approach to software but fruitful efforts in the other areas are underway.

Preliminary work on the feasibility of a commonality approach was done by FSD at its facility in Houston as part of an effort to use software from the Shuttle Ground Based Space System (GBSS) in the Shuttle Payload Operations Control Center (POCC), each using an IBM System/370 Model 168. These efforts were advanced in Gaithersburg during the proposal phases for both the Global Positioning System, a spacebased radio frequency navigation and positioning system, and the Data System Modernization program, an upgrade for the SCF. Results of these efforts showed that IBM's 303X and 4300 series processors provide solutions to hardware requirements, while significant amounts of existing software produced by other IBM divisions and FSD offer a large common software foundation for realtime command and control system applications (1).

- **RISK MINIMIZATION**
  - Utilization Of Proven Hardware and Software Improves Development Schedules
  - Early Availability Of Experienced Personnel
- **REDUCED LIFE CYCLE COST**
  - Common Hardware And Software Baselines Minimize Development Costs
  - Common Facilities For Software Development
  - Common Maintenance Procedures For Hardware/Software
  - Reduced Personnel/Training Costs
- **OTHER CONSIDERATIONS**
  - Interoperability
  - Reliability
  - Flexibility
  - Growth

Figure 1. The advantages of commonality are present in the acquisition, activation and operational phases.

SYSTEM LEVEL SOFTWARE

The common software concept is shown in Figure 2. The nucleus of the diagram contains the software (over five million source lines) which is common to GBSS, DSM, and the GPS Master Control Station. This includes existing IBM products: the Multiple Virtual Storage (MVS) operating system, the Time Sharing Option (TSO), the System Productivity Facility (SPF) and the Virtual Telecommunications Access Method (VTAM). Also included in this common nucleus is existing software developed by FSD for the Shuttle Ground Based System: the Program Management Facility (PMF), a library management system used to control software during its development; and the Advanced Statistics Collector (ASC), a performance measurement tool used to fine-tune the realtime system.

Extending this nucleus of common software is the realtime executive (RTX), another GBSS-based product which adds to the standard MVS operating system those features required for a real-time processing environment. Still another layer of commonality is represented by FSD software capabilities in display management, data base management and test driver/scenario generation. The final layer of software commonality is represented by kernels of software in the applications which are typical of space-oriented realtime command and control systems—telemetry, trajectory, command and control.

SYSTEM SOFTWARE

- FEDERAL SYSTEMS DIVISION
  - Program Management Facility
  - Advanced Statistics Collector
- OTHER IBM DIVISIONS
  - Multiple Virtual Storage Operating System
  - Time Sharing Option
  - System Productivity Facility

APPLICATION EXECUTIVE

APPLICATION SERVICES

- DISPLAY MANAGEMENT
- DATA BASE MANAGEMENT
- TEST DRIVER/SCENARIO GENERATION

APPLICATION KERNELS

- TELEMETRY
- TRAJECTORY
- COMMAND
- CONTROL

Figure 2. The common software concept starts with a nucleus of vendor provided (commercial) operating system and program products, extends to a realtime application executive, includes application services and, finally, encompasses the application kernels. This concept provides software packages that can be used on multiple projects.

THE APPLICATION EXECUTIVE

The commonality approach to software is based upon the concept of the realtime application executive (RTX). RTX provides several advantages that are key to commonality and transportability. They are:

– It provides the extensions to the commercial operating system that are necessary to meet realtime processing requirements such as high data rates, extended support periods, special error recovery procedures and system restart/failover.

– It provides alternate means of performing operating system functions when those provided by the commercial system cannot meet the stringent realtime performance requirements. Storage, resource and work management are typical examples.

– It helps to insulate the applications from the hardware configuration by providing hardware support and external data interfaces.

The significance of RTX is that it allows the use of unmodified commercial operating systems and helps the applications to be hardware configuration independent (Figure 3). When modifications to the software are necessary due to configuration changes, they can usually be made in RTX rather than in the operating system or applications. Since RTX is about 150 thousand source lines of code versus several million each for the operating system and applications, the benefits of this approach are apparent.

- OPERATING SYSTEM
  - Initialization/Termination
  - Dynamic Resource Allocation
  - Telecommunications/External Interfaces
  - Data Management Services
  - Access Methods
  - Utilities
- APPLICATION EXECUTIVE
  - Realtime Initialization/Termination
  - Work Management
  - Time Management
  - Buffer Management
  - Data Array Management
  - Lock Management
  - Status Reporting
  - Common Input/Output Services
  - Display Management
  - Time And Data Routing
  - Error Recovery
  - Logging
  - Checkpoint/Restart/Switchover
- APPLICATIONS
  - Telemetry Processing
  - Command Processing
  - Network Control
  - Trajectory
  - Systems Simulation
  - Performance Analysis

Figure 3. The distribution of system control functions shows how the application executive provides realtime extensions to the operating system and insulates the applications from the hardware configuration.

COMMONALITY DEMONSTRATIONS

The feasibility of a commonality approach to realtime command and control systems software was demonstrated in three related activities which used the Ground Based Shuttle System as a base. In February 1980, the GBSS programs, (over 1,600,000 source lines) were transported from NASA's mission control center in Houston (where they were developed by FSD and executed on IBM System/370 Model 168 processors) to the IBM facility at Gaithersburg, Maryland. Only minor modifications to the display hardware interfaces were required in order to successfully execute these large, complex, realtime programs in both IBM 3033 and 4341 processors under a standard MVS operating system, thereby demonstrating the upward and downward compatibility of the system. These programs were used in Gaithersburg as a base for the GPS benchmark in March 1980; for the SOPC upward compatibility demonstration in April 1980; and for the DSM Stage 1 demonstration, in November 1980. All of these efforts were highly successful.

As a result of this work, both GPS and DSM will be using all software elements of the common nucleus, plus an enhanced version of the realtime executive and new display software. Enroute to this achievement, major difficulties were overcome, including the establishment of a common programming language and a common set of programming standards for both the DSM and GPS projects.

APPLICATION SOFTWARE

The preceding discussion focused on the operating system and the application executive. However, a significant effort to find common application software was also performed. While there was some success, the application area has not yet been as fruitful as the others.

The common application software analysis addressed DSM, GPS and GBSS. The GBSS software is the current baseline for SOPC so that the analysis essentially addressed three programs (viz., DSM, GPS/MCS and SOPC) which are to be co-located at CSOC. While co-location is not necessary to obtain software commonality benefits, it does enhance them.

Since virtually all currently envisioned space command and control systems have requirements for command, telemetry and trajectory applications, these areas were chosen for analysis.

Command

The command area was broken into 48 distinct functions. The functions ranged from general support software, such as programs to accept and format user inputs, to software which is highly command-specific, such as programs to generate data groups for uplinking to a vehicle.

Of the 48 functions examined, 18 were judged potentially common across DSM/GBSS/GPS. A total of 24 functions were evaluated potentially common to DSM/GPS, with six of these being non-GBSS functions. Results are summarized in Figure 4.

Total number of functions examined	=	48
Number common to DSM/GBSS/GPS	=	18
Number common to DSM/GPS, but not to GBSS	=	24
Size of DSM/GBSS/GPS common functions in thousands of source lines of code	=	84

Figure 4. The results of the command commonality analysis show that DSM and GPS have potential for a common source of about 50% of the functions.

Telemetry

The telemetry area was analyzed as 32 separate functions which included such areas as initialization, data stream processing, manual inputs processing and delogging. Nineteen of the functions were judged potentially common to DSM/GBSS/GPS. No functions were determined to be common to DSM/GPS exclusive of GBSS. Summary results are shown in Figure 5.

Total number of functions examined	=	32
Number common to DSM/GBSS/GPS	=	18
Number common to DSM/GPS but not GBSS	=	0
Size of DSM/GBSS/GPS common functions in thousands of source lines of code	=	350

Figure 5. The results of the telemetry commonality study show good potential for common application software.

Trajectory

The Trajectory area is unique among the applications being considered in this report for two reasons:

i) The GBSS trajectory application is vehicle-specific to a larger degree than are GBSS command and telemetry; that is, specific Space Shuttle characteristics, such as thrust modeling for engines specific to the Shuttle, are scattered throughout the GBSS trajectory code, rendering it difficult for conversion for other projects' use.

ii) Among the three areas being considered, trajectory is the only one which is already being implemented, in part, from a common base on the DSM and GPS projects.

For these reasons, the trajectory analysis began not by looking for potentially common functions from the GBSS system, but rather by looking at the DSM/GPS "common base" referred to in (ii) above, namely the Goddard Trajectory Determination System (GTDS). GTDS is a highly general, FORTRAN-based, satellite tracking and orbit analysis system which has been in use at the Goddard Space Flight Center for several years.

It provides many of the functions needed for any space tracking system, such as ephemeris generation and differential correction, and offers the user a large amount of control over the specific parameters which govern the execution of the function.

Both the generality of GTDS and the fact that it has been an operating satellite tracking system for years make it an attractive base for any new satellite tracking application. For this report, GTDS was broken into nine logical functions, ranging from functions of the general support nature, such as file formatting and reporting, to highly trajectory-specific functions, such as differential correction. Six of these functions were evaluated as common to DSM and GPS. Two of the three remaining functions exist in DSM, but not in GPS. A summary of the results appears in Figure 6, where the thousands of source lines of code number represents FORTRAN code.

An important event for future generalized trajectory work was the development of the DSM Tracking and Orbit Determination mathematical specifications (2). This document, based on GTDS documents (3) which served a similar function for that system, is sufficiently thorough and general to provide an excellent starting point for creation of a generalized trajectory functional specification.

In addition to the GTDS functions surveyed in this report, there are important trajectory functions for which common development may be important and feasible for future software systems. Two such functions are attitude determination and maneuver planning. No attempt has been made at this point to assess their commonality potential in a quantitative fashion, but attention to both functions is essential in the development of functional specifications for a generalized trajectory system.

Total number of GTDS functions	=	9
Number common to DSM/GPS/GTDS	=	6
Number common to DSM/GTDS only	=	8
Size of DSM/GPS/GTDS common functions in thousands of source lines of code (FORTRAN)	=	45

Figure 6. The results of the trajectory commonality study indicate that the Goddard Trajectory Determination System (GTDS) along with the existing DSM system (Advanced Orbital Ephemeris System) would be a good choice as a trajectory base for DSM and that decision was made and is being implemented on the DSM contract. Although Ground Based Space System (GBSS) trajectory software has a lot of functional commonality with GTDS, it doesn't appear in the comparison because the implementation is very vehicle specific and makes general use difficult.

OTHER COMMONALITY AREAS

The preceding discussion has centered almost entirely on software. However, the commonality effort has successfully addressed several other areas. Some of the more significant are discussed below.

Display and Control Functions

One of the generic characteristics of a command and control center is a display and control system. This system is used to view incoming or computed data and to format and send commands. Typical equipment includes cathode ray tubes, plasma displays, touch panels, joy sticks, function keyboards and plotters. The display requirements seemed to hold excellent promise for a common approach and as a result of a subsequent study, GPS and DSM are using a common mission console and common software. Furthermore, analysis has shown that the GPS/DSM common mission console meets almost all of the salient requirements of the SOPC digital television equipment. This appears to be a fruitful area and is the subject of an ongoing effort.

Adapting Commercial Processors to Command and Control Interfaces

Control centers in general face the problem of interfacing commercial processors with standard interfaces to the outside world of telemetry,

tracking, command and displays which often have specialized and different interfaces. The solutions to this problem are complex and varied and tend not to be useful for multiple projects. A typical approach is to use a set of mini-computers but this tends to be data rate limited and to incur significant software costs. A more generalized solution is to adapt a commercial data controller with a set of plug-in cards on the outboard side. This approach has the advantages of high data rates, more general usage, little software impact and being nearly a commercial solution. Effort in this area is continuing.

Communications Interface System

A significant portion of a communications interface system is the telemetry, tracking and command processing system and is a basic component of control centers. Typical functions performed by a "front end" include preprocessing, recording and distribution of telemetry, tracking, command, video, voice and miscellaneous data both internally and externally to the control center. Analysis has shown that the DSM (hence, SOC) front end is a subset of the one baselined for SOPC and can be augmented to meet SOPC requirements. The DSM based solution is potentially simpler, thus less expensive to acquire and operate. Additionally, the co-location of SOC and SOPC offers such benefits as reduced maintenance and training. As before, further analysis in this area is continuing.

Summary

Further development of the commonality concept is being pursued by a common systems development group established by FSD in Gaithersburg and in other FSD locations such as Houston. An in-house effort, the group's primary objective is to develop system-level software which can be used across multiple present and future command and control projects.

Studies convincingly show that commonality makes both sound technical and business sense. Preliminary analysis of the potential for commonality in application software such as telemetry, trajectory, and command and control has shown the possibility of establishing common application software kernels which could be used across projects. Thus, the potential exists for carrying this commonality beyond the system-level software into application programs. In the hardware area, multiple project use of special equipment, a trend towards a more commercial solution and common man-machine interfaces hold great promise.

Commonality is a concept that has matured within FSD and is currently in practice, reducing cost and technical risk and improving software scheduling.

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THE CONSOLIDATED SPACE OPERATIONS CENTER (CSOC) COMMUNICATIONS ACQUISITION

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ABSTRACT

The Consolidated Space Operations Center (CSOC) is being built in the Colorado Springs area to conduct DOD space operations. Its Satellite Operations Complex and its Shuttle Operations and Planning Complex will be functionally similar, respectively, to the Air Force Satellite Test Center at Sunnyvale, California, and the NASA Johnson Space Center in Houston. CSOC Communications (CSOC-CS) will be common to both missions and will tie CSOC to Air Force and NASA nodes and networks.

CSOC-CS faces a number of challenges: functional replication, multiple network interfaces, and evolution of other systems and philosophies. The problem is further compounded by an existing system that is still evolving and by a compressed schedule, as CS is the lead CSOC segment.

INTRODUCTION

Space, the final frontier of mankind, has become a center of activity as the nations of the world exploit it through better communications, weather forecasting, geological exploration and other uses that enrich the lives of their citizens. The United States has done all of these, as well as maintaining a large number of space assets to assure its national security as depicted in Figure 1.

CSOC

Today the National Aeronautics and Space Administration (NASA) and Department of Defense (DOD) operate two separate global networks. Because of economic, operational and mission considerations and to lessen the burden on NASA, DOD has decided to build and operate a Consolidated Space Operations Center (CSOC).

CSOC, while providing enhanced capabilities to meet future traffic demands, will certainly fulfill the nation's need for an endurable and secure facility for the command and control of DOD Shuttle and satellite missions.

CSOC will be located at Colorado Springs and is the flagship of the new Space Command and the centerpiece of the emerging Air Force Satellite Control Network (AFSCN). Figure 2 shows this perspective. Since a communications capability is the heart of an effective command and control system, the success of the AFSCN depends on the availability of an endurable communications network.

CSOC Segments

CSOC, from the procurement point of view, is divided into seven segments, as shown in Figure 3, with the Communications Segment (CS) as the cement that holds the segments together. In the external sense, CS provides extensive connectivities to every critical node of the AFSCN, as shown in Figure 4.

Communications Segment (CS)

CSOC communications provides complete capabilities to satellite missions and Shuttle missions and designated capabilities to colocated program elements (CPE) such as the Global Positioning System (GPS) and connectivities to National Command Authority (NCA) through SPADOC/NCMC. As the cornerstone of CSOC activation and test activities, the CS must be acquired promptly, managed properly, and designed, developed, installed and operated in a most cost-effective manner.

CHALLENGES

The Air Force Satellite Control Network must work harmoniously to satisfy its designated missions. The key nodes of the

network must also share each other's responsibilities under certain conditions. The current concept of operations calls for such a capability, and it is referred to as interoperability between paired nodes. For example, the Air Force Satellite Control Facility (AFSCF) must be fully interoperable with the Satellite Operations Complex (SOC) of CSOC. Similarly, Johnson Space Center (JSC) which currently operates the Shuttle, must be interoperable with the Shuttle mission portion of CSOC, or Shuttle Operations and Planning Complex (SOPC).

AFSCN's success also largely depends on successfully integrating the full capabilities of the elements of the network. Therefore, compatibility, commonality, and standardization are key concepts in CSOC definition. The concepts apply not only to current systems but also to other parallel developments such as the Data System Modernization (DSM) program for AFSCF, the NAVSTAR Global Positioning System (GPS) and the Defense Meteorological Satellite Program (DMSP).

It is indeed a challenge to design a system under these circumstances. To understand this challenge and to provide a framework for understanding the applied solutions, it is useful to picture the challenge in terms of the three major facets or dimensions of the design problem. This is illustrated in Figures 5 and 6. These are (1) fitting into both the DOD and NASA worlds, (2) functional replication, and (3) time. Whenever we have to specify or design a new element for the CS system, we have to address these dimensions.

Fitting into Two Worlds

Over the years NASA and DOD have followed their own paths and have achieved separate levels of maturity in communications capabilities. Each evolved around different architectural and environmental considerations. For example, the NASA Telemetry, Tracking and Command (TT&C) frequencies and signal structures were markedly different from that of AFSCF's mainstay, the Space Ground Link Subsystem (SGLS) TT&C system. Other differences exist in operations and maintenance philosophies, security and data privacy concepts, and management techniques. All these differences have had an effect on equipment design. Thus, the first CS question we answer is "Will it fit into the NASA world, or the DOD world, or some combination of both?"

Functional Replication

Here is the simplest solution available. Buy an exact duplicate of selected pieces of equipment from the AFSCF and Johnson Space Center, install and test with no problems, and be within budget. Unfortunately, in most cases this just won't work for several reasons:

1. Design may be location dependent.

2. Equipment may not be available.

3. Functional requirements may be different.

4. Current designs may have flaws.

5. Simpler, cheaper, or more efficient solutions may be available.

We have to take all these into account and attempt to strike a cost versus performance balance, selecting that design which gives us the required functions at lowest cost and schedule risk. This has led to the term "functional replication," to describe that twilight zone between complete off-the-shelf duplication and totally new design where all required functions are satisfied.

Time

A third basic question we have to consider is "What will the rest of the world look like when we bring our communications segment into operation?" This leads us into some speculation on programs we know about, as well as some crystal ball gazing into some very hazy areas. The AFSCF itself is currently undergoing change: the DSM program, new wideband connectivities and modifications to the AFSCF Remote Tracking Sites are some examples. The colocated program elements are also undergoing changes, such as the incorporation of DMSP terminal capabilities into RTS, and introduction of Advanced Remote Tracking Stations (ARTS). The birth of Space Command and the modernization of NCMC, including the introduction of the Defense Satellite Communications System (DSCS) terminal into the NCMC is also important to note. NASA too is moving away from reliance on its Goddard Spaceflight Tracking and Data Network (GSTDN) to Tracking and Data Relay Satellite System (TDRSS) based connectivities. The growth systems to be considered include MILSTAR and the common mobile control systems which require the usage of higher TT&C frequencies. CSOC-CS must remain compatible in this fast moving world.

The hazy areas include conceptual and philosophical matters which are in a state of flux and may or may not be the same in the future as they are today. Figure 7 points out some of these issues.

INITIATIVES

To meet the challenges we have just identified, many initiatives have been taken. We will highlight nine of these and show how they apply to the challenges. The initiatives fall into three categories: management, acquisition, and engineering (Figures 8 and 9). None of the initiatives represent brand new ideas, but rather are extensions or adaptations of good management and engineering practices tailored to our application and environment.

MANAGEMENT

The three management initiatives we are highlighting are (1) assigning administrative communications to Air Force Communications Command (AFCC), (2) use of an integration contractor, and (3) use of functional working groups and committees (Figure 10).

AFCC Role

In line with our philosophy of functional replication and avoiding unnecessary new development wherever possible, we identified the administrative communications area, i.e., admin telephone switch, communications message center, AUTOVON, AUTODIN, and AUTOSEVOCOM connectivity, as an area where a standard approach would work best. As a result, the SPO has selected AFCC as a partner to help implement admininistrative communications. AFCC has a wealth of experience in this area, fully understands administrative communications, and has a mature operations and maintenance philosophy. With AFCC as a partner, we get the additional bonus in being able to cross-fertilize ideas with a command whose forte is operations and maintenance of communications systems.

Integration Support Contract

In the spring of 1982, Air Force Space Division awarded the CSOC Integration Support Contract (CISC) to TRW. This has brought on board extensive expertise to complement the skills resident in the CSOC Program Office. A large part of the system integration effort is defining and engineering the interfaces necessary to fit into the DOD and NASA worlds and making it work as a system. TRW is also solidifying various philosophical issues and has authored systems engineering, maintenance and support concepts.

Groups and Committees

We have established many working groups and steering committees, some of which are shown in Figure 10. We have found these groups especially useful in solving many of the functional problems which cut across CSOC product lines. In many cases, these groups also provide the forums to raise and work issues crucial to interfacing CSOC with the external world. Additionally, the groups have provided impetus to solidifying and settling philosophical issues early enough to be incorporated into the design.

ACQUISITION

The nature of the design challenges has also affected our acquisition approach. Ideas have been implemented which have worked well in other programs. These are (1) two-phase strategy, (2) use of analytical tasks, and (3) an incremental support capability concept (Figure 11).

Two-Phase Strategy

Rather than a single contract for the entire Communications Segment (CS) acquisition, we are going to develop the system in two phases. The first phase will be a one year definition effort with two contractors competing in parallel to provide a set of specifications for the CS. Then, one of these designs will be selected for Phase 2 implementation, which will span 60 months. Several advantages accrue from this approach. It allows considerable investigation and solidification of other product lines and concepts prior to actually selecting a design approach; it injects elements and creativity into the design process; and it permits the use of timely special studies in areas that are weak or hazy. These special studies are called analytical tasks, and are discussed separately.

Analytical Tasks

It has always been easier to identify weak or hazy areas than it has been to find their solutions. Therefore, we have used the analytical task as a device to generate these solutions. Each contractor in Phase One will analyze and provide recommended solutions for fifteen problem areas that are identified in the Statement of Work and are as shown in Figure 11. These fifteen represent the most difficult design areas and require the closest scrutiny and study before design approaches are finalized.

Incremental Support Capabilities

This is our "buy it by the pound" approach for the Communications Segment (Figure 12). The CS is required to support different capabilities at different times. In general, the DOD world will be connected first and CSOC will become operational in phases before the NASA world is integrated into the system. This means that other CSOC segments will be in different stages of design and development when phase two of the CS contract begins. Rather than design and build everything at once, the CS will be activated in increments depending on when its capabilities and functions are required. This permits for better design solidification of the out-year elements before communications are designed for them. In addition, paying for the capabilities as we need them produces a more acceptable funding profile.

ENGINEERING

Good engineering solutions generally arise from (a) identification of existing design limitations, (b) establishment of design considerations, and (c) the enumeration of detailed requirements. These are shown in Figure 13. A subset of the existing design limitations is shown in Figure 14. The design considerations are extracted from the mission needs while the design requirements synthesis will be via a combination of the mission needs statement and the derivation of functional characterizations from the operations concept, within the technology constraints. Figure 15, for example, is a partial look at the data rates/needs of several mission/program elements that must be addressed in the engineering solution.

So the problem reduces to this. "What is the balancing act that the CS designer must put together to satisfy the combined needs of DOD and non-DOD users?" Figure 16 depicts some of the network related issues, while Figure 17 shows that the communications processing designer must be provided with a specific set of data for his design and not a catalog or a shopping list.

These problems provide but a sample of the size and scope of the engineering issues to be resolved before CSOC becomes a reality. To meet the engineering challenge now and in the future, we have instituted three important engineering ground rules (Figure 18):

(1) Use Pre-Planned Product Improvement (P^3I),

(2) Capitalize on other programs, and

(3) Maintain Transparency of Communications.

Pre-Planned Product Improvement (P^3I)

P^3I has been a most important concept in our acquisition effort. It simply means designing with a built-in capability for future growth. One of the tools used to ensure that the concept is implemented is designating it an analytical task for Phase One of the acquisition. In this effort, both contractors will look at the future architecture of space systems and will identify specific areas in which to apply the P^3I concept. P^3I provides the best insurance that CSOC will be a system for the future.

Capitalize on Other Programs

Wherever possible, CSOC communications is capitalizing on other programs, using facilities, designs, studies, or options wherever possible to keep from re-inventing the wheel, to get the best bang for the buck, and to promote commonality. For example, we are piggy-backing a NASA contract to purchase multiplexer/demultiplexer (MDM) for the NASA communications links; and we are using a Defense Satellite Communications System (DSCS) facility serving other DOD missions for some CSOC connectivity. There is also a complicated options linkage between the CSOC program and other AFSCF programs where both may capitalize on each other's efforts.

Communications Transparency

This concept, simply stated, is that communications systems should be kept as standard, common and flexible as possible by avoiding embedded mission or location dependent functions and by maintaining common standards on all communications links. This is a key initiative which allows interoperability (control of range assets by several operations centers within the same organization) and internetting (allowing an operations center to control spacecraft using ground stations belonging to another organization). Implicit in this concept is that CSOC must speak a language common to the nodes to which it is connected. For this reason, CSOC is providing format conversion where necessary to maintain transparency to the user.

The transparency concept also enhances survivability of the AFSCN by commonality of alternative paths. For example, in Figure 19, the alternate paths to Remote Tracking Sites still remain,

even if a primary route out of CSOC via DSCS becomes unavailable or inoperative. Thus, the transparency concept helps us to perform our mission better, even under adverse conditions.

SUMMARY

In meeting the challenges presented by CSOC communications acquisition, many initiatives have been implemented, nine of which have been presented in this paper. As a result of the efforts thus far, a communications architecture has emerged (Figure 20). We are confident that the basic architecture is sound and that it will continue to evolve successfully to meet the needs of CSOC as a system for the 1980's and beyond.

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None.

Acronyms

A	Aerospace Corporation, Aerospace Corp
ADMIN	Administration, Comm
AF	Air Force
AFCC	Air Force Communications Command
AFSCF	Air Force Satellite Control Facility
AFSCN	Air Force Satellite Control Network
ARTS	Advanced Remote Tracking Station
AUTODIN	Automatic Digital Network
AUTOSEVOCOM	Automatic Secure Voice Communications
AUTOVON	Automatic Voice Network
B	Bits
B SPEC	Specifications per MIL-STD-490
B/B	Baseband
BPS	Bits Per Second
CA	Contract Award
CASC	CSOC Activation Steering Committee
CCB	Configuration Control Board
CCSC	CSOC Communications Steering Committee
CDR	Critical Design Review
CH	Channel
CISC	CSOC Integration Support Contract
CMD	Command
COMM	Communications, direct-current (dc) frequencies through light wave frequencies
Common Mobile	Common Mobile Control System
CPE	Colocated Program Elements
CP. P,	
CP PK	Camp Parks, California
CS	Communications Segment, CSOC
CSOC	Consolidated Space Operations Center
CSOC-CS	Consolidated Space Operations Center - Communications Segment
D	Day
DD 250	A DOD Form to announce the acceptance of an item/entity/product/system
DET	Detection
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DOMSAT	Domestic Satellite Systems
DRG	Data Routing Group
DSCS	Defense Satellite Communications Group (II = two; III = three)
EPAC	East Pacific
FS	Facility Segment
FDC	Formatting and Data Conversion Subsystem
FD	Fort Dietrich
GPS	Global Positioning System
GSFC	Goddard Spaceflight Center
GSTDN	Goddard Spaceflight Tracking and Data Network
GFE	Government Furnished Equipment
ICWG	Interface Control Working Group
I/F	Interface
ILSMT	Integrated Logistic Support Management Team
INF	Information
ISC	Incremental Support Capability
I&CO	Integration and Check Out
JCS	Joint Chiefs of Staff
JSC	Johnson Space Center
KBPS	Kilo (Thousand) Bits Per Second
KSC	Kennedy Space Center
LANT	Atlantic
M	Minutes
M-22	Mission Twenty-two
MB	Million Bits
MBPS	Million Bits Per Second
MDM	Mux-Demux
MILSTAR	Military Satelllite Network (Strategic & Tactical)
MS	Milli-Second
NAVSTAR	Navigation Satellite
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NCA	National Command Authority
NCMC	NORAD Cheyenne Mountain Complex
NCS	Network Control Segment
NMCS	National Military Command System
NORAD	North American Aerospace Defense Command
NW	Northwest Station, West Virginia
N/A	Not Applicable
OCMS	Operations Control and Monitor Subsystem
OPS	Operations, Communications
OPSEC	Operations Security
O&M	Operations and Maintenance
$\emptyset_1$	Phase One of CS Acquisition, 12 Months
$\emptyset_2$	Phase Two of CS Acquisition, 60 Months
PDR	Preliminary Design Review
P3I	Pre-Planned Product Improvement
P/L	Payload
PROP	Proposal for CS Phase Two
RCB	Requirements Control Board
RECONF	Reconfiguration
REQTS	Requirements
RFP	Request for Proposal
RTS	Remote Tracking Site/Station - GTS Guam Tracking Site/Station - HTS Hawaii Tracking Site/Station - VTS Vandenberg Tracking Site/Station - TTS Thule Tracking Site/Station - OTS Oakhanger Tracking Site/Station - NHS New Hampshire Tracking Site/Station
SAC	Strategic Air Command
SCN	Satellite Control Network
SDR	System Design Review
SEC	Security
SEC WKG GP	Security Working Group
SGLS	Space Ground Link Subsystem (DOD)
SOC	Satellite Operations Complex
SOPC	Shuttle Operations and Planning Complex
SPADOC	Space Defense Operations Center
SPADOC-4	Fourth Increment Update to SPADOC System
SRR	System Requirements Review (I = one, II = two)
SS	Support System Segment
STC	Satellite Test Center
SUPPORT	Support System Segment of CSOC
TDRSS	Tracking and Data Relay Satellite System
TOM	Transition, Operation, and Maintenance
TRW	A Company called TRW
TT&C	Telemetry, Tracking and Command
TX	Transmitter/Transmission
USAF	United States Air Force
VAFB	Vandenberg Air Force Base
VSS	Validation Support Segment
WB MDM	Wideband Mux-Demux
WPAC	West Pacific
WSGT	White Sands Ground Terminal
YQ	Organizational Symbol at USAF/AFSD, Program Office for CSOC
#	Number
427M	A Modification Program at NCMC

Figure 1. The Final Frontier

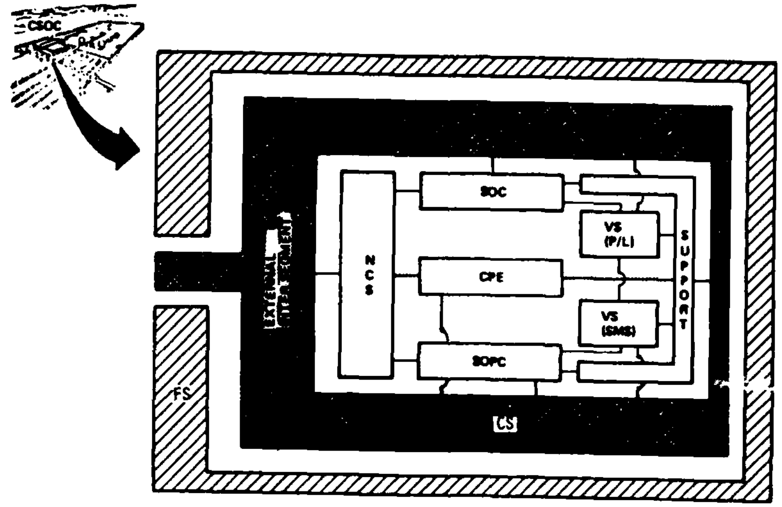


FIGURE 3 COMMUNICATIONS PERSPECTIVE

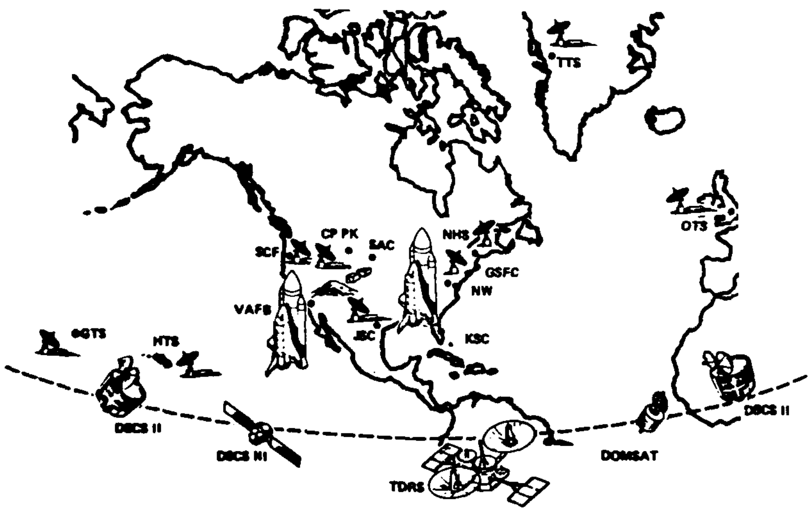


FIGURE 2. AFSCN CONFIGURATION

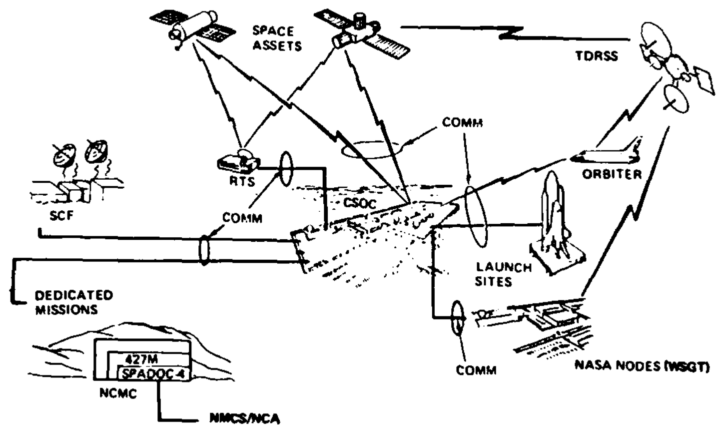


FIGURE 4 COMMUNICATIONS CONNECTIVITY

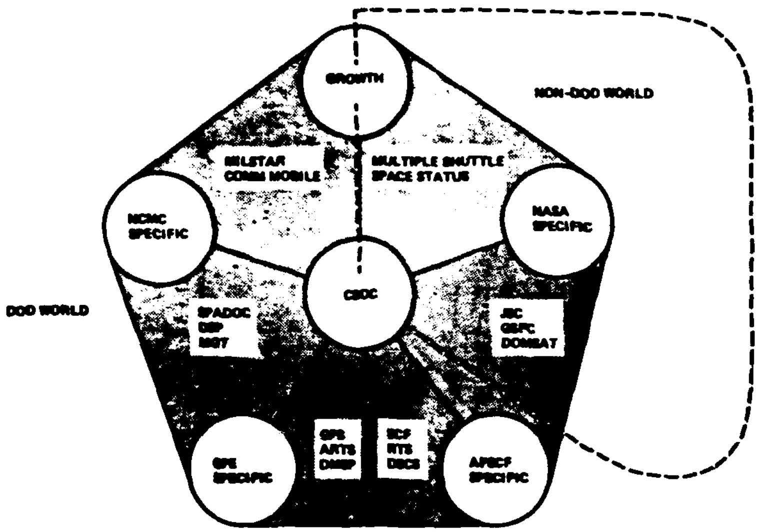


Figure 6. Fitting into Multiple Worlds Means Constant Vigilance

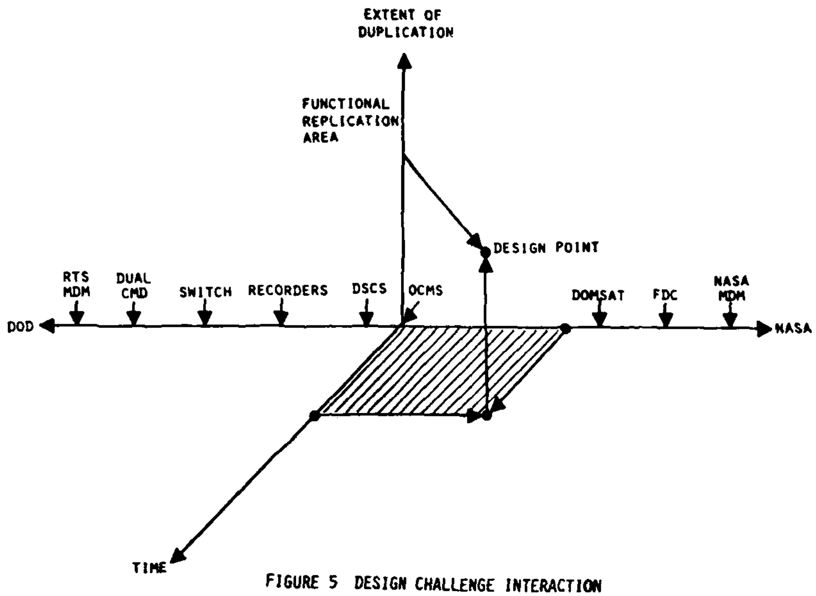


FIGURE 5 DESIGN CHALLENGE INTERACTION

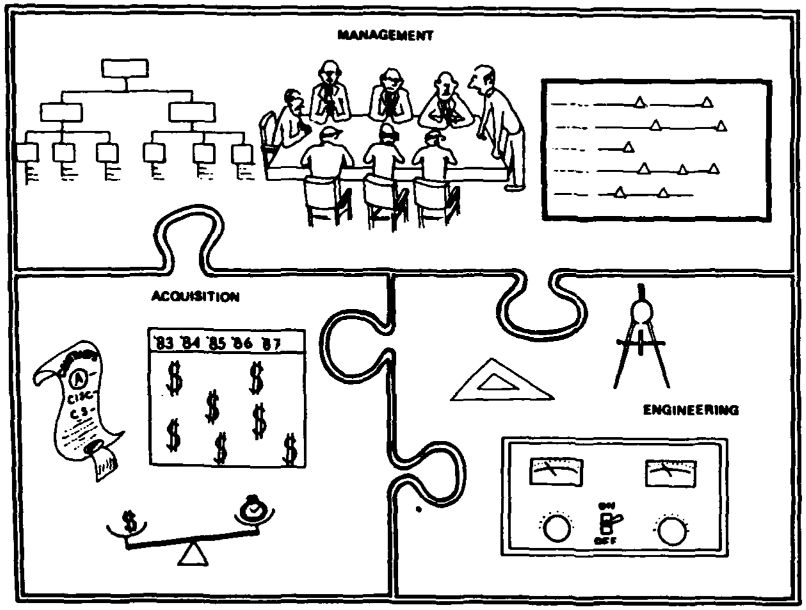


FIGURE 8 MANAGEMENT, ACQUISITION AND ENGINEERING

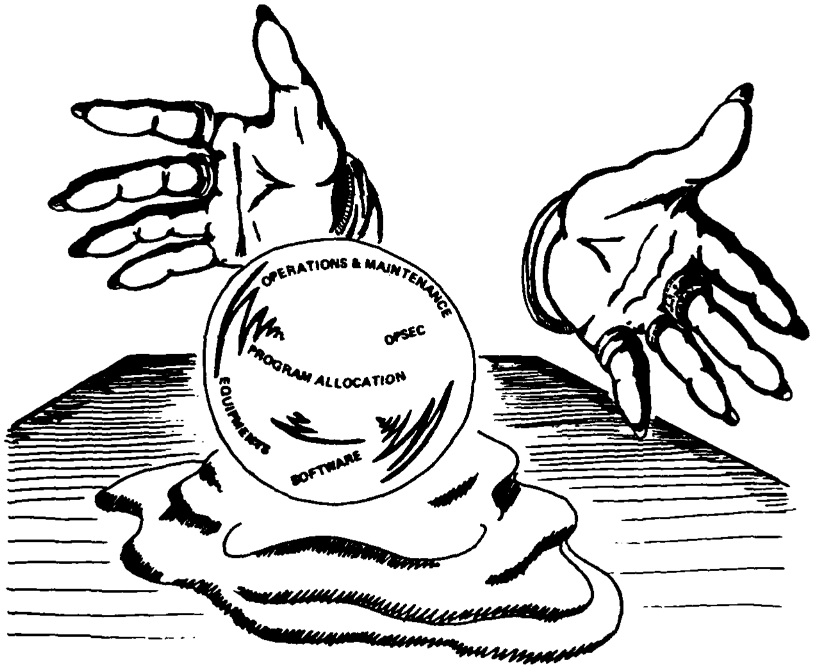
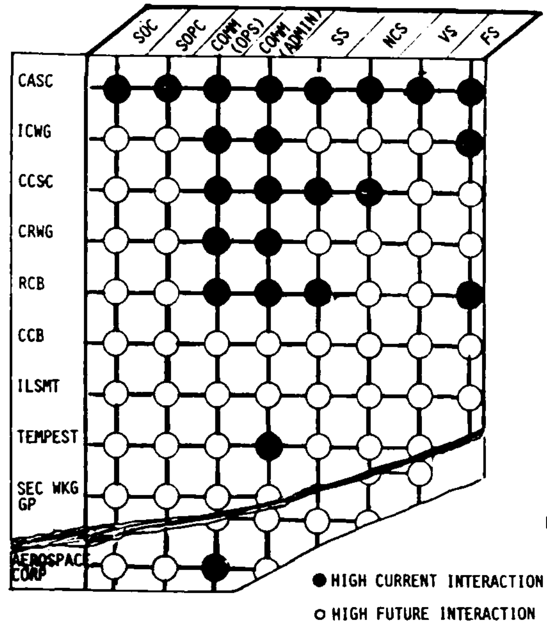


Figure 7. Philosophical Differences

	INITIATIVES								
	MANAGEMENT			ACQUISITION			ENGINEERING		
CHALLENGE DIMENSIONS	AFCC ROLE	CISC	GROUPS	2Ø	AT	ISC	P^3I	OTHER PROGRAM	TRANS-PARENCY
TWO WORLDS DOD - NASA	L	H	H	L	H	L	L	H	H
FUNCTIONAL REPLICATION	H	H	L	H	H	L	L	H	L
TIME	H	H	H	H	H	H	H	L	L

APPLICABILITY TO CHALLENGE: H = HIGH/EXTENSIVE, L = LOW/NOMINAL

FIGURE 9 APPLICABILITY OF SOLUTIONS

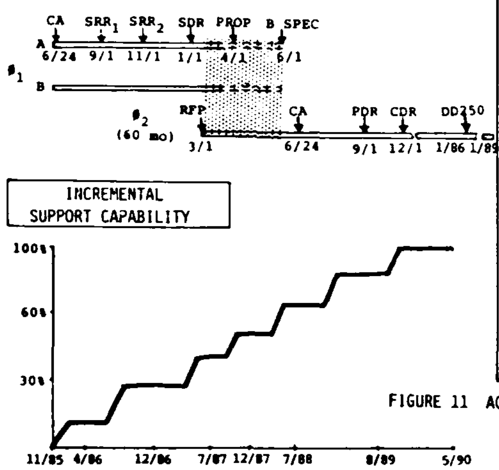


AFCC ROLE
- EXPERIENCE
- MATURE O&M PHILOSOPHY
- CROSS-FERTILIZATION

INTEGRATION CONTRACTOR
- INTERFACES
- CONCEPTS
- INTEGRATION & TESTING

FIGURE 10 MANAGEMENT INITIATIVES

TWO PHASE STRATEGY



INCREMENTAL SUPPORT CAPABILITY

ANALYTICAL TASKS

1. CONNECTIVITY
2. SECURITY & DATA PRIVACY
3. SWITCH
4. CONTROL AND MONITOR
5. NASCOM/AFSCN NET
6. AFSCN W-B MDM
7. INTERFACE ANALYSIS
8. SPADOC INTERFACE
9. DATA RATE UPGRADE
10. STC SWITCH
11. SCF WIDEBAND
12. PRE-PLANNED PRODUCT IMPROVEMENT (P^3I)
13. COST TRADEOFFS
14. PHASE 2 CONTRACT TYPES
15. PRODUCIBILITY

FIGURE 11 ACQUISITION SOLUTIONS

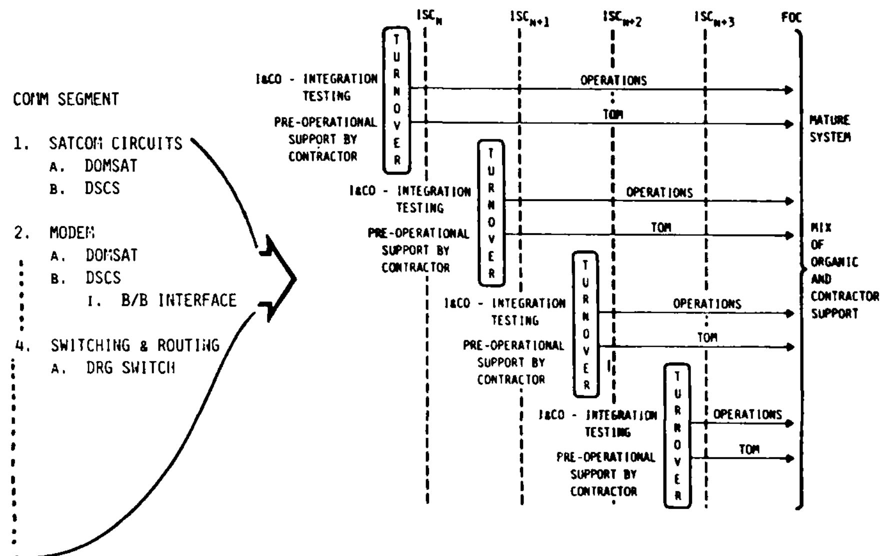


FIGURE 12 INCREMENTAL INTEGRATION AND TURNOVER

CURRENT DESIGN LIMITATIONS

- DSIS
- SWITCHING
- DRG SIZE
- SECURITY
- MDM'S

CONSIDERATIONS

- SATELLITE CONTACTS: 500/D [250/D]
- # OF RECONFIGURATIONS:140/D [120/D]
- # OF RTS TO BE CONNECTED:18 + [13]
- TELEMETRY LOAD: 525 MB [30 MB]
- RELIABILITY: > .998 [N/A]
- PROTOCOL: VARIOUS

REQUIREMENTS

- RECONFIGURATION TIME: < 2M [15M]
- AGGREGATE DATA RATE: 10 MBPS [3 MBPS]
- TIMING ACCURACY: <± 1MS [≤ ± 1 MS]
- RECORDING: 63 + CH/SIMULTANEOUSLY
- DATA RATE: VARIOUS

FIGURE 13 CURRENT DESIGN, FUTURE DESIGN CONSIDERATIONS & REQUIREMENTS

[NUMBERS IN PARENTHESIS REFER TO CURRENT CAPABILITIES]

TODAY'S SHUTTLE COMM CONFIGURATION

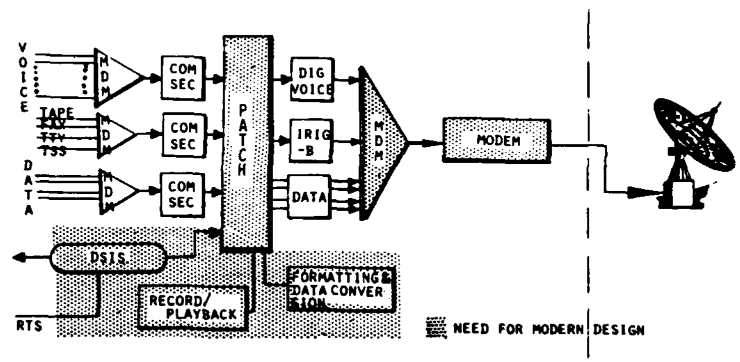


FIGURE 14 EXAMPLE OF EXISTING DESIGN LIMITATIONS

MISSION/PROGRAM	CHARACTERISTICS: THROUGHPUT DATA RATE (KBPS)	DUTY CYCLE	# REMOTE TERMINALS	RECONF NEED
SOC	1536	SPORADIC	13 + 2 + 5	< 5 MTS
SOPC	3072	100%	1 + 7	
GPS	9.6	DEDICATED	4 + 6	
SPADOC	9.6?	CONTINUOUS		
ARTS	5000	SPORADIC		
MILSTAR	10,000 ?	SPORADIC		
DMSP	2660	SPO[illegible]		

FIGURE 15 COMMUNICATIONS MUST SUPPORT SEVERAL EMERGING REQUIREMENTS

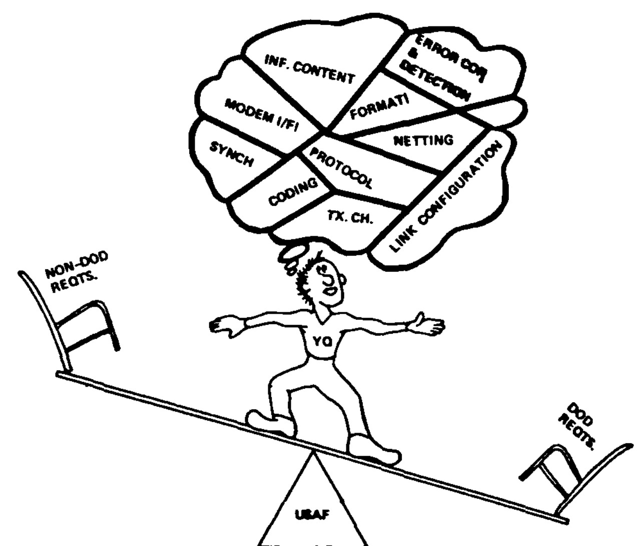


Figure 16 Engineering Balancing of Network Issues

LINK CONFIGURATION	POINT-TO-POINT; MULTI-DROP SPX; DPX; HDPX: CENTRALIZED; FEDERATED	ERROR RECEPTION	ARQ; ENQ; NAKAI; ACKM; FEC;
MODEM INTERFACE	TTY 20/60MA; MIL-STD-188C; RS 232 ; V. 35 (WB)	FORMAT	BIT; BLOCK
SYNCHRONIZATION REQUIREMENTS	ASYNCHRONOUS; SYNCHRONOUS; BI SYNCH; FRAME SYNCH;	TRANSMISSION CHARACTERISTICS	RATE; BER; DELAY B'ER
INFORMATION CONTENT	ASC11; EBCDIC DES	NETTING	LAN (SDLC, ETHERNET, ARC) BROADBAND (WANGNET, ETC.)
ERROR DETECTION	CONTEXT; REDUNDANCY CHECK BLOCK; CHARACTER PARITY	PROTOCOL	CHARACTER ORIENTED (BI SYNCH, ANSI X3.28...) BIT ORIENTED (HDLC; ANSI X3.66/ADCCP; SDLC/SNA)

FIGURE 17 ENGINEERING SOLUTION ALTERNATIVES

A. PRE-PLANNED PRODUCT IMPROVEMENT (P^3I)

- GROWTH POTENTIAL IDENTIFIED
- SPECIFIED LOOK AT THE FUTURE ARCHITECTURE

B. CAPITALIZE ON OTHER PROGRAMS

- PIGGY BACK BUYS
- OPTIONS ON CONTRACTS
- COMM LINKS EXPLOITATION

C. TRANSPARENCY

- INTEROPERABILITY
- INTERNETTING
- SURVIVABILITY

FIGURE 18 SUMMARY OF ENGINEERING SOLUTIONS

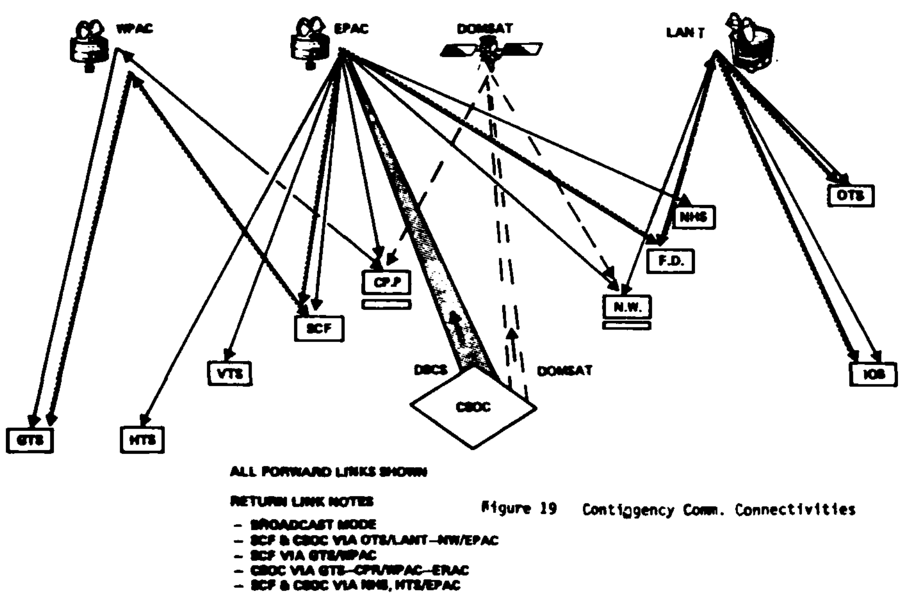


Figure 19 Contiggency Comm. Connectivities

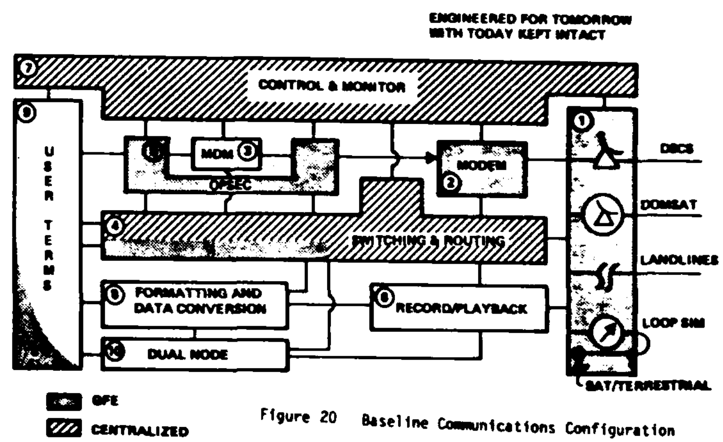
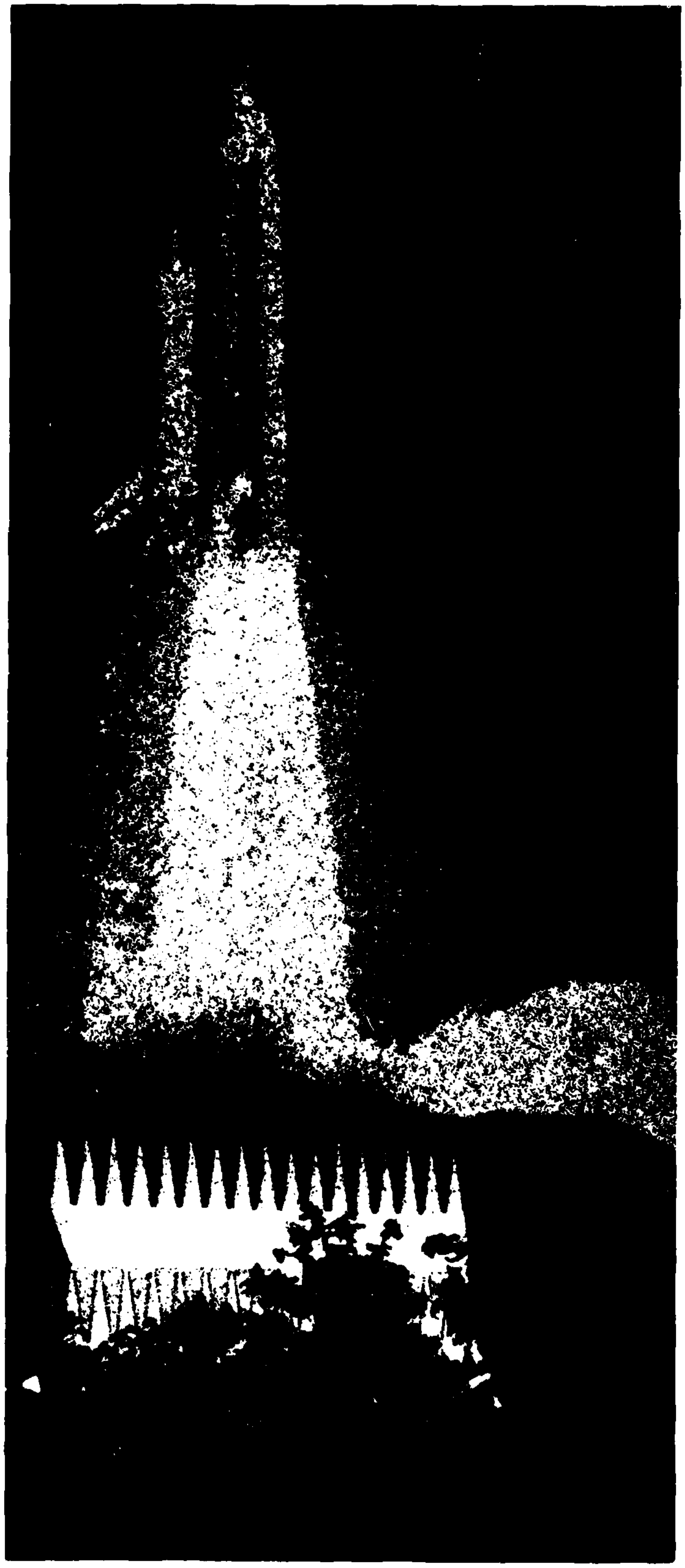


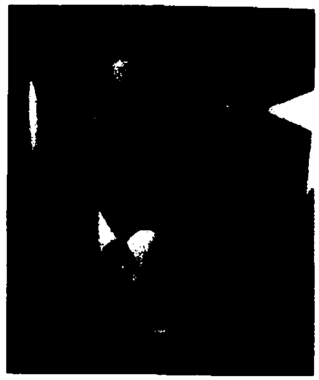
Figure 20 Baseline Communications Configuration



Banquet Guest Speaker

General James V. Hartinger
Commander, SPACE Command

Banquet Guest Speaker



Gen James V. Hartinger
Commander
SPACE Command

General James V. Hartinger is Commander of the USAF Space Command (SPACECOM) and Commander in Chief of the North American Aerospace Defense Command (NORAD), with both headquarters at Peterson Air Force Base, CO.

General Hartinger is from Middleport, Ohio, where he was drafted into the Infantry in July 1943 and attained the grade of sergeant. Following World War II, he entered the United States Military Academy at West Point, New York. Upon graduation in 1949, he received a bachelor of science degree and was commissioned as a second lieutenant in the United States Air Force.

General Hartinger has been a career long fighter pilot. He attended pilot training at Randolph AFB, TX, and Williams AFB, AZ, where he graduated in August 1950. He then was reassigned as a jet fighter pilot with the 36th Fighter Bomber Wing at Furstenfeldbruck, Germany, and in December 1952 joined the 474th Bomber Wing at Kunsan Air Base, Korea, where he flew his first combat missions in the F-84 Thunderjet.

In July 1953, he returned to Williams AFB as a gunnery instructor, and in August 1954 was transferred to Stewart AFB, NY, as a fighter pilot and air operations officer in the 331st Fighter Interceptor Squadron. During this period, he attended Squadron Officer School at Maxwell AFB, AL.

In June 1958, General Hartinger began a four year tour in the Directorate of Requirements, HQ USAF, in the Pentagon. After receiving a master's degree in business administration at the George Washington University in 1963, he was assigned to Hickam AFB, HI, in the Directorate of Plans, HQ Pacific Air Forces.

General Hartinger graduated from the Industrial College of the Armed Forces at Fort McNair, Washington, D.C., in June 1966. Thereafter, he received F-4C Phantom replacement training with the 43rd Tactical Fighter Squadron at MacDill AFB, FL, and proceeded to Vietnam. From December 1966 to December 1967, he was assigned to HQ 7th Air Force at Tan Son Nhut Air Base, during which time he completed more than 100 aerial combat missions.

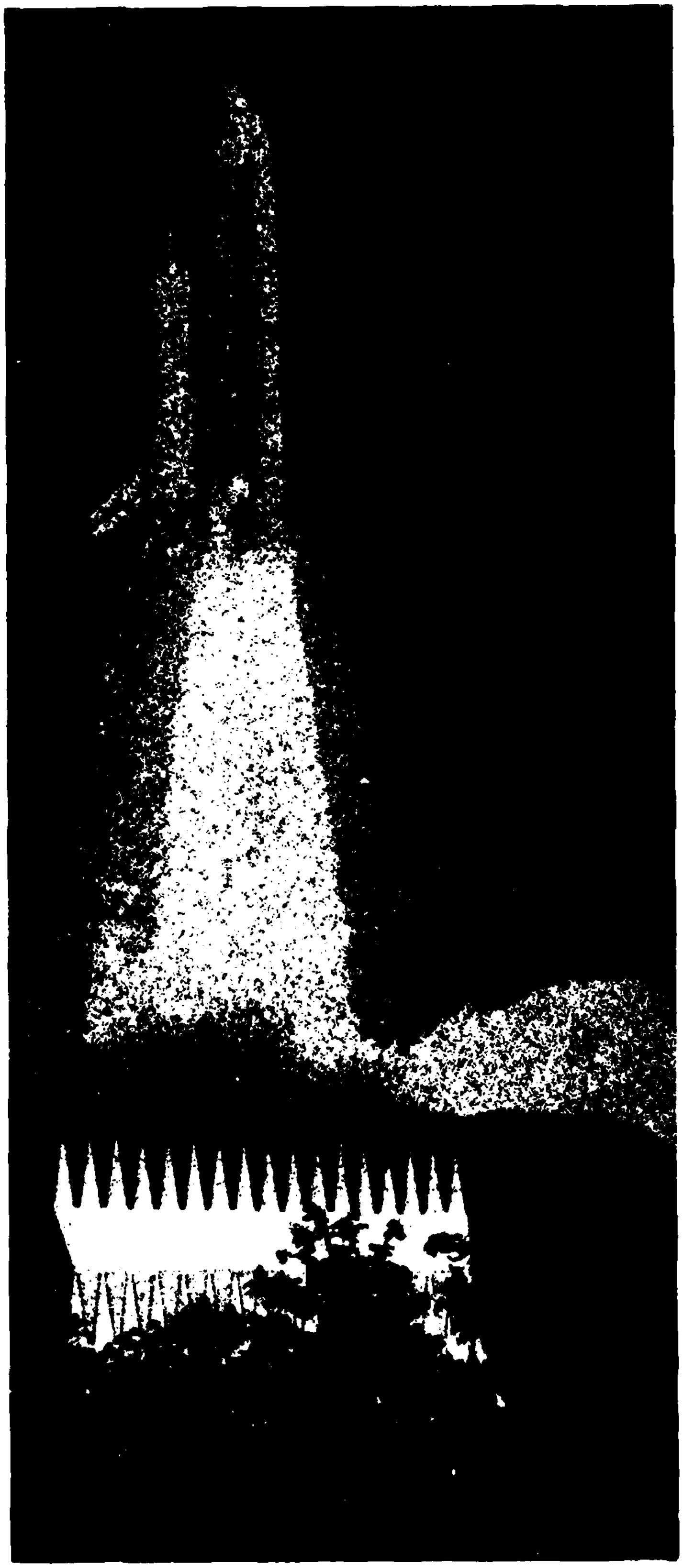
In 1968, General Hartinger was the F-111 test director at Nellis AFB, NV, and then assumed command of the famed "Flying Tigers," the 23rd Tactical Fighter Wing, at McConnell AFB, KS.

General Hartinger became Deputy Chief of Staff/Plans at North American Air Defense Command, Ent Air Force Base, CO, in June 1970 and then moved to Maxwell AFB, AL, in May 1973, as Commandant of the Air War College.

From 1975 to 1980, General Hartinger was Commander of both Tactical Air Command Air Forces, 9th Air Force at Shaw AFB, SC, and 12th Air Force at Bergstrom AFB, TX. He became CINCNORAD on 1 January 1980, and Commander, SPACECOM, on 1 September 1982.

His military decorations and awards include the Defense Distinguished Service Medal, the Distinguished Service Medal with one oak leaf cluster, Legion of Merit with one oak leaf cluster, Distinguished Flying Cross, Air Medal with eight oak leaf clusters, Air Force Commendation Medal, and Combat Readiness Medal. He is also an honorary Doctor of Military Science.

General Hartinger is married to the former Mickey Christian of Mullens, WV, and has three children: Jimmer, Kris, and Mike.



Session 6

Policy, Strategy and Legal Aspects of Space

Session Chairman: Col. R. B. Giffen, *USAFA*

The Papers

Peaceful Use and Self Defense in Outer Space

Soviet Military Capabilities in Space

***Space Weapons:* A Real-World Perspective for the Military Planner**

AD P002155

PEACEFUL USE AND SELF DEFENSE IN OUTER SPACE

A. J. BUTLER, Lieutenant Colonel*/

HEADQUARTERS, UNITED STATES AIR FORCE

ABSTRACT

This article examines the international legal restrictions on the military use of outer space and how those restrictions have been interpreted by the two major space powers in their actual or projected utilization of space for military-related purposes. It also discusses the fragile nature of the legal regime which has been created by international treaties. These treaties will probably be suspended or terminated during time of hostilities between the parties.

INTRODUCTION

In the not too distant past, the international legal community could take pride in the fact that they had been successful in establishing a rudimentary legal regime governing certain activities by States in outer space. The success of the Committee on the Peaceful Uses of Outer Space (COPUOS) in developing certain broad legal principles is considered by many members of the legal profession as one of the finest examples of law being in the vanguard of a new environment. There is no doubt that the spectacular success, as reflected by the numerous nations that have become parties to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies,1/ was a brilliant accomplishment of the world legal community. The fact that the Outer Space Treaty was followed shortly by three companion treaties2/ added to the prestige and relevance of international space law. Only in the last few years, with the difficulty posed by some controversial provisions in the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies and the various intractable issues pending before COPUOS, has the momentum abated.3/

With the four treaties on outer space activities having been generally accepted by a significant portion of the world community, the international legal community began the task of interpreting the vague terminology that had been necessary to incorporate into the treaties due to the consensus procedure utilized by COPUOS. Articles in all languages cascaded forth attempting to analyze the somewhat obscure legal regime that had been created.4/ One area that attracted attention was the attempt to define what was meant by the words "peaceful use" as those terms appear in the Outer Space Treaty. While those academic exercises were occuring over the definition of peaceful use, the world space powers were giving clear meaning to such concepts by the actual military uses that they were making of the outer space environment.

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* Attorney At Law, Lieutenant Colonel, Office of The Judge Advocate General, International Law Division, Headquarters, USAF, Washington DC. Member: American Society of International Law, International Institute of Space Law, I.A.F.

The opinions and conclusions expressed in this paper are those of the author and do not necessarily represent the views of the Department of Defense, the Department of the Air Force or the United States Government.

PEACEFUL USE

The words "peaceful uses of outer space" are not a legal term of art. Many international lawyers have attempted to turn what is essentially a general philosophical description into specific legal restrictions. Essentially the meaning of "peaceful use" varies from one viewer's perspective to another's as well as from one document or treaty to another. Therefore, because it is not a term of art, one must look to other sources to ascertain the meaning. In this regard, international lawyers have failed to give sufficient importance to the actual practice of the states in arriving at a workable and acceptable definition of the peaceful use clause as contained in the Outer Space Treaty.

Initially there were two schools of thought on the meaning of peaceful use. The first held that in the context of the Outer Space Treaty, peaceful use meant non-aggressive use of outer space. Under this view the only military restrictions were those specifically stated in the applicable multilateral and bilateral treaties, including the United Nations Charter, to which individual states were parties. The second school of thought equated peaceful use to non-military uses of outer space. This later definition was quickly determined to be rather impractical. It was early realized that virtually all uses of outer space could have military application. Legal scholars then eventually posed the question in a different manner. They stated that instead of attempting to classify a particular space activity as military or non-military, a better approach would be to ask whether the activity in question is consistent with the requirements of international law, including the United Nations Charter.5/ It should be remembered that international law, including the United Nations Charter, does not prohibit military activity as such. It only prohibits the threat or use o. force and acts of aggression. The United Nations Charter also specifically reiterates the inherent right of self-defense.

SUBSEQUENT PRACTICES AND INTERPRETATION OF TREATIES

In order to give this latter approach some meaning, the actual practice of nations that have the capability of operating militarily in the outer space environment becomes vitally important in the interpretation of the terms of the applicable treaty. This, of course, may raise the objection that the practices of a few states that are parties to a multilateral treaty cannot provide a definitive meaning to the terms found in a multilateral treaty.6/ However, because of the unique environment of outer space, the relatively few states that can utilize outer space for military activity and the manner in which the legal rules governing outer space activities have been developed, the actual practices of the two nations that effectively use outer space for military related purposes should be given great weight, if not controlling weight, to the definition of such nebulous terms as "peaceful use".

Section III of the Vienna Convention of the Law of Treaties, promulgates some general rules for the interpretation of international agreements. Under Article 31 (3) it states, in part:

> "There shall be taken into account, together with the content.
>
> . . . .
>
> (b) Any subsequent practices in the application of the treaty which establishes the agreement of the parties regarding its interpretation."

The use of the actual practice of States in attempting to interpret the meaning of an agreement is most frequently called "practical" or "conventional" interpretation. This so-called "principle of subsequent conduct" refers to any behavior, subsequent to the entry into force of an agreement, which appears to be relevant or useful in determining the continuing consensus of the parties.8/ Lord McNair stated such principle in the following manner:

> "The contracting parties may themselves have attached a particular meaning to the terms of a treaty either impliedly by a long course of conduct or by expressed agreement and in either case this agreed meaning may be either a bona fide interpretation of an obscure term or an attempt to substitute a new stipulation for the original one."9/

In general, it has been stated that a major purpose in examining the subsequent actions of the parties is that of obtaining an exceptionally reliable source for determining their genuine shared expectations. The weight to accord subsequent practices of the parties will vary from case to case, but no respected commentator on interpretation has failed to endorse the principle,

although some have cautioned against placing too much emphasis upon such evidence, especially if it appears to conflict with the initial expectations.[10]

Judge Alvarez has commented that "a treaty. . .that once has been established acquires a life of its own. Consequently, in interpreting it, we must have regard to the exigencies of contemporary life rather than the intentions of those who framed it."[11] And finally, McNair states that any theory of interpretation should be one which is favorable to the freedom of states and places the less restriction on its liberty of action.[12]

In evaluating these views of the importance of subsequent practice, it becomes readily apparent that the actual practice of the space powers becomes fundamentally important to any interpretation of terms found in the treaties regarding the regime of outer space. This subsequent practice theory of interpretation reflects the true expectations of the space powers in the contemporary utilization of space for military defensive purposes.

ACTUAL PRACTICE

What has been the practice of the two space powers since the Outer Space Treaty entered into force? While it is somewhat difficult to determine exactly the extent of military use of outer space by the space powers due to security classifications, one can obtain a fairly good idea of the present practices by reviewing current media reports of such activity. There appears to be good media evidence that the Soviets have been able to develop an operational anti-satellite system, and the Americans have stated that they are pursuing the development of their own anti-satellite system.[13] During the recent Falkland/Malvinas and Lebanese crises, it was reported that both the Soviets and the Americans were actively utilizing reconnaissance satellites to obtain military intelligence relating to the conflicts.[14] There is little question that both countries' military are more and more relying on space based systems for communication, navigation, early warning, and treaty verification. It has been estimated that 70% of Soviet satellites are purely military in their application with an additional 15% of their space activity sharing a dual role with the non-military sector. This leaves only 15% of their space activity to civil scientific endeavors.[15] The United States has indicated that over 40% of the cargo of the space shuttle originates with the United States military, and for the next fiscal year, the U.S. military budget for space related projects will exceed the budget for NASA.[16] The United States Air Force only recently announced the creation of a separate Space Command in order to more effectively manage the growing investment in military space systems.[17] Both powers appear to be heavily involved in research related to space based laser systems.[18] The litany of military uses of outer space by the Soviets is extensive and probably limited only by the present state of the art and the few restrictions found in international agreements. The utilization of space for self-defensive purposes has taken place and with it the interpretation of peaceful use has become a fait accompli.

SPECIFIC RESTRICTIONS

A discussion of the restrictions contained in both multilateral and bilateral treaties involving the space powers is necessary in order to realize the present limited restrictions on the military use of outer space. It is first important to reiterate the concept that international law is generally proscriptive in nature--that is, what is not prohibited is normally allowed. Consequently, very few military activities are barred from operation in the outer space environment.

The most widely accepted prohibition concerning military activity in space is found in the Outer Space Treaty. Article IV of that treaty prohibits the following military related activity: (1) Not to place in orbit around the earth, install on the moon or any other celestial body, or otherwise station in outer space nuclear or any other weapons of mass destruction and (2) Not to establish military bases, installations, or fortifications, test any type of weapons or conduct military maneuvers on the moon or other celestial bodies.[19] Weapons of mass destruction include biological and chemical weapons, but do not include laser and particle beam weapons systems as these systems can be considered "point" weapons and not indiscriminate weapons of mass destruction.[20]

Two other important multilateral treaties are the Treaty Banning Nuclear Weapons Tests in the Atmosphere, In Outer Space and Under Water and the Convention on the Prohibition of Military or any other Hostile Use of Environmental Modification Techniques.[22] The

Limited Test Ban Treaty bans all nuclear explosions in outer space. The Environmental Modification Treaty specifically applies to the outer space environment and prohibits the military or other hostile use of environmental modification techniques as the means of destruction, damage or injury to any other State Party, if the usage has widespread (several hundred square kilometer area), long lasting (approximately a season) and has severe effects (serious or significant disruption or harm to human life, natural and economic resources or other assets). Environmental modification techniques are defined as any technique for changing the dynamics, composition or structure of the earth or of outer space through the deliberate manipulation of the natural processes. This treaty does not prohibit research, development and testing of environmental modification techniques.

In addition to the above multilateral treaties that restrict military activity in outer space, there are certain bilateral treaties between the United States and the Soviet Union that further restrict their military operations in space. The treaty on the Limitation of Anti-Ballistic Missile Systems, with Associated Protocol, expressly prohibits the development, testing or deployment of space-based ABM systems and components.23/ An ABM system is defined as "a system to counter strategic ballistic missiles or their elements in flight trajectory." Under the terms of this same treaty, the Parties agree not to interfere with each other's national technical means (NTM) of verification. NTM is the cryptic reference to, among other things, imaging satellites used for treaty monitoring to insure compliance with the ABM treaty. Similar NTM provisions are found in the SALT I and SALT II agreements.

Another multilateral international agreement that has important application to the military uses of outer space is the United Nations Charter.24/ The Outer Space Treaty specifically made the United Nations Charter part of the legal regime of outer space. The two most important parts of the Charter that directly affect military operations in space are Article 2(4) and Article 51. The former states that "All Members shall refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any state or in any other manner inconsistent with Purposes of the United Nations." Article 51 preserves the customary right of self-defense.25/

EFFECT OF HOSTILITIES ON TREATIES

A problem that is often ignored when discussing the restrictions on the military uses of outer space is the effect of hostilities on the continuing application of the terms of the treaties concerned. Practically all the discussion of the military application of outer space revolves around the military uses in peacetime. However, it is of crucial importance to military research, development and contingency planning for the effect of hostilities on certain treaties be appreciated. It is of similar importance for international lawyers to acknowledge this situation in order that future agreements will address this anomally.

There is general agreement that the outbreak of hostilities does not *ipso facto* terminate all treaties. The termination or suspension of treaties during hostilities depends on a treaty's nature, terms, subject matter and the intent of the parties. Other than these broad guidelines, current international legal principles are not very helpful in this area.

If it is clearly stated in the terms of the treaty or it is obvious from its content that the treaty is to apply or to become operative during hostilities, then there is little problem. For example, the 1907 Hague and the 1949 Geneva Conventions relating to the conduct of hostilities are clearly treaties of this type. However, of the treaties concerning restrictions on outer space activity by the military, only the Environmental Modification Treaty by its own terms remains in effect during hostilities.26/

At the other end of the spectrum is the arms limitation or disarmament type of treaty. By their very nature, such treaties are incompatible with the state of armed conflict and would be suspended or terminated during hostilities. In this category would be the ABM Treaty27/ and the Nuclear Test Ban Treaty.28/

Somewhere in between the treaties that are specifically made applicable during hostilities and the treaties that are clearly incompatible with armed conflict falls the Outer Space and related Treaties.29/ One must, then, resort to the intentions of the parties to determine whether the terms of the treaty are compatible with hostilities. The issue of the effect of hostilities on the Outer Space Treaty, apparently

was never discussed during negotiations. However, the provisions of Article IV of the Outer Space Treaty would appear to be incompatible with hostilities, as such provisions are basically concerned with the areas of disarmament and demilitarization zones. Consequently, during hostilities it would seem that each party would have the right to determine the extent to which it considered itself bound by the obligations of Article IV. Thus, if this provision is deemed to be incompatible with the state of armed conflict, it could be suspended, allowing, for example, the orbiting or stationing in outer space weapons of mass destruction and the militarization of celestial bodies. The same would appear true of the other companion treaties.[30] For example, the concept that an astronaut is an "envoy of mankind," and the requirement that the holding state immediately return him to his home country, would quickly change in time of hostilities to converting an astronaut who is found in hostile territory, to either the status of prisoner of war, a civilian detainee or even perhaps he could be considered a spy. Depending on various factors, the astronaut could then only rely upon the provisions of one of the 1949 Geneva Conventions and not on the provisions of the Rescue and Return Treaty. The Registration and Liability treaties would also be one of the first casualties of hostilities between the parties, as the terms of these treaties are not compatible with an armed conflict situation.

It is recognized that the above discussion may be an over simplification of the effect of hostilities on space related treaties. Many countries, because of the unique environment of outer space, would take the view that supension of Article IV of the Outer Space Treaty restricting military activity affects all parties to the treaty. They could argue that the many references to peaceful purposes and the concept of using space for the benefit of all mankind, along with the multilateral nature of the treaty, require that the treaty remain in force and effect during periods of armed conflict. However, this opposing view is left to other authors to explore. It is merely stressed that the basic test in this area is the compatibility of a treaty's provisions with a state of hostilities. Under this criterion, it does not appear that the Outer Space and its three companion treaties would survive the test and, thus, would be suspended between belligerents during a period of hostilities.

CONCLUSION

The legal regime that has been created for outer space activities and the attempt to limit certain military applications is indeed a fragile one. The restrictions during peacetime are very few and, in fact, allow for a broad use of space for non-aggressive military purposes. The nebulous nature of the restrictions on military space activities is further made apparent by the possible suspension or termination of such treaties during times of armed conflict between the parties.

However, the international space law community should regard this present state of the legal regime of outer space as a challenge. It should look for areas in which the outer space regime could be stabilized by developing practical and workable legal principles in areas in which mutual agreements can be realistically obtained. However, initially, I believe it is important to appreciate the limitations that inform this area. The most important is to acknowledge that disarmament of outer space, while a noble principle, is directly related to disarmament on the earth and therefore should not be addressed in isolation. The second factor to understand is that the space powers have by their subsequent conduct, provided the clearest interpretation of the present state of international law vis a vis the use of outer space for military purposes. Once these premises are acknowledged, the focus can then be on developing additional rules and regulations that will assist in stabilizing the outer space regime and limiting the possibility that outer space will be utilized for hostile purposes.

FOOTNOTES

1. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (hereinafter cited as the Outer Space Treaty) Jan. 27, 1967, 18 U.S.T. 2410, T.I.A.S. 6347, 610 U.N.T.S. 205 (effective Oct. 10, 1967).

2. Agreement on the Rescue of Astronauts and the Return of Objects Launched Into Outer Space (hereinafter cited as the Rescue and Return Agreement), April 22, 1968, 19 U.S.T. 7570, T.I.A.S. 6599, 672 U.N.T.S. 119 (effective Dec. 3, 1968); Convention on International Liability for Damage Caused by Space Objects, (hereinafter cited as the Liability Convention), March 29, 1972, 24 U.S.T.

2389, T.I.A.S. 7762, (effective Oct. 9, 1973); Convention on Registration of Objects Launched Into Outer Space (hereinafter cited as the Registration Convention) January 14, 1975, 28 U.S.T. 695, T.I.A.S. 8480 (effective Sep. 15, 1976).

3. Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, U.N. GAOR, 34th Sess. (1979), Supp No. 20 (Doc A/34/20); See also Cocca, "The Advance of International law Through the Law of Outer Space", 9 J. Space L. 13-20 (1981) for discussion of some current issues.

4. See K. Lee, World Wide Space law Bibliography, (1978) for an exhaustive listing of space law articles.

5. USAF News Release, Oct. 31, 1978, Speech by MGen Reed, to the American Astronautical Society, Houston, Texas. See also Gorove, "Arms Control Provisions in the Outer Space Treaty: A Scrutinizing Reapprasial", 3 Ga J. Int & Comp L. 714, (1973).

6. There are approximately seven entities that have the capability of launching their own satellites. They are Peoples' Republic of China, European Launcher Development Organization (ELDO), Japan, India, Orbital Transport and Raketen Aktiengesellschaft (OTRAG), United States of America, and Union of Socialist Republics. Stine, Confrontation In Space, (1981) pp. 34-35.

7. Vienna Convention on the Law of Treaties, May 23, 1969, 3 International Legal Materials 679.

8. McDougal, Lasswell, Miller, The Interpretation of Agreements and World Public Order, (1967) p 133.

9. McNair, The Law of Treaties, (1938) p. 252.

10. McDougal et al, supra note 8, at 216.

11. Id page 219.

12. McNair, supra note 9 at 254.

13. NY Times, June 6, 1982 at 1.

14. Wash. Post, June 7, 1982 at A-20.

15. "Soviets Outspending US on Space by $3-4 Billion", Aviation Week and Space Technology, July 19, 1982 at 28.

16. Phil. Inquirer, May 23, 1982 at 1.

17. Wash. Post, June 22, 1982 at 2; Baltimore Sun, June 22, 1982 at 7; NY Times, June 22, 1982 at 19.

18. Wall Street J., July 8, 1982 at 3; Henderson, "Space Based Lasers", Astronautics and Aeronautics, May 1982 at 44-53; Aviation Week and Space Technology, May 3, 1982, at 13.

19. Supra note 1, Article IV.

20. Stine, supra note 6 at 5.

21. Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under Water, Aug 5, 1963, 14 U.S.T. 1313; T.I.A.S. 5433; 480 U.N.T.S. 43 (effective Oct 10, 1963).

22. Convention on the Prohibition of Military or any other Hostile Use of Environmental Modification Techniques, with Annex, May 18, 1977, 31 U.S.T. 333; T.I.A.S. 9614 (effective Jan 17, 1980).

23. Treaty on the Limitation of Anti-Ballistic Missile Systems, May 26, 1972, 23 U.S.T. 3435; T.I.A.S. 7503 (effective Oct 3, 1972).

24. Charter of the United Nations, T.S. 993; 3 Bevins 1153, June 26, 1945, (effective Oct 24, 1945).

25. Article 51 of the United Nations Charter states in part: "Nothing in the present Charter shall impair the inherent right of individual or collective self-defense if an armed attack occurs . . . ." See also DeSaussure and Reed, "Self-Defense---A Right in Outer Space", 7 USAF JAG L. Rev. 33-45, Sep-Oct, 1965.

26. Supra, note 22.

27. Supra, note 23.

28. Supra, note 21.

29. Supra, note 1 and 2.

30. Supra, note 2.

SOVIET MILITARY CAPABILITIES IN SPACE

Nicholas L. Johnson

Teledyne Brown Engineering

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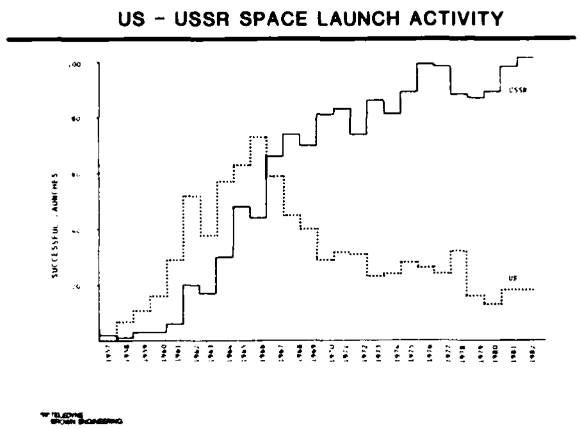


Figure 1: The Soviet Union continues its high launch rate despite improvements in satellite longevity.

the Soviet Union has taken the lead in the number of space missions and today bests the U.S. in launch activity by a ratio of 5:1. The next illustration (Figure 2) depicts the scope of the Soviet space threat.

Numbers alone, however, do not adequately reflect the differences between American and Soviet space assets. It is recognized that U.S. satellites are generally complex, long-lived and deployed in few numbers while equivalent Soviet networks are comprised of many satellites simple in design and with shorter lifetimes. For example, in 1982 the U.S. placed just three satellites in orbits characteristic of photo reconnaissance missions while the Soviets launched 36 such satellites. Likewise the majority of Soviet satellites are placed in easy-to-reach low Earth orbits, while more than 70% of American satellites reside in more difficult 12- or 24-hour orbits (Figure 3).

Although we are tempted to ascribe these differences to less advanced Soviet technology, there are other factors also at work here. The first is economy. By mass-producing relatively simple satellites and launch vehicles the Soviets can avoid the astronomical costs associated with many U.S. space missions. The standardization and commonalty of many subsystems, such as propulsion and attitude control, further reduces expenditures

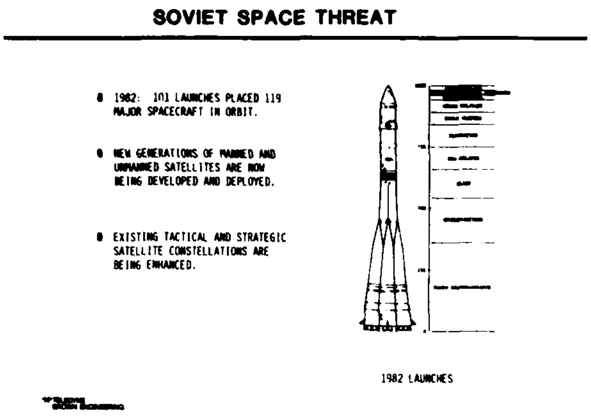


Figure 2: Soviet space systems pose a direct threat to American terrestrial and space assets.

at a modest sacrifice in capability.

More important, however, are the implications of the Soviet deployment philosophy on war-time survivability. The proliferation of Soviet satellites in low Earth orbits presents any enemy with a multitude of targets. One-on-one engagements by conventional interceptors then become less attractive both from a weapon-to-target cost ratio and from a timeliness standpoint. Furthermore, evidence indicates that, as a result of the large numbers of spacecraft and launchers produced, the Soviets maintain a stockpile of replacements which are available for launch on short notice. Thus, if the Soviets were to lose satellites to hostile action, most constellations could be replenished in short order. By contrast the U.S. is ill-equipped to replace any satellite quickly enough to support most postulated terrestrial conflicts.

An additional advantage to the Soviet system is its reliance on launch vehicles of tactical or strategic missile origin (eg. SS-5 and SS-9) for many satellite launchings. Conceivably these satellites could be orbited from non-historical launch sites in times of crisis. Meanwhile America is rapidly coming to rely on the Space

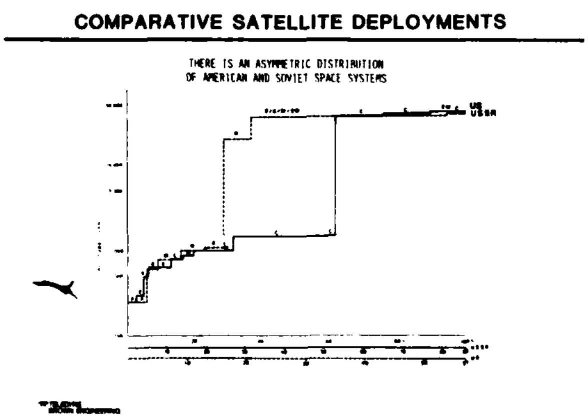


Figure 3: Unlike American satellites, the majority of Soviet satellites reside in low Earth orbits.

Transportation System which is constrained to operate from two highly vulnerable sites near the coasts.

The remainder of this presentation will highlight individual Soviet space programs of interest to this audience. By far the largest Soviet space effort is devoted to photographic reconnaissance. As noted earlier, 36 reconnaissance spacecraft were orbited last year. Twenty-six of these remained in space less than two weeks. The remainder had lifetimes somewhat longer, usually 4 to 6 weeks. The longer-lived models first appeared two years after the Yom Kippur Middle East War in which the Soviets were forced to launch seven photo satellites in three and a half weeks. This was necessary because the intelligence data could only be analyzed after the spacecraft returned to Earth. The newer model satellites reportedly carry multiple reentry capsules for film retrieval on demand.

Interestingly, the next illustration (Figure 4) shows that as the average lifetime of Soviet photographic satellites has increased during the past decade the number of missions conducted each year has remained at the highest levels. Consequently, the cumulative annual mission days continues to climb and the simultaneous operations of two, three or even four photo satellites is not uncommon. The reluctance to reduce the annual launch rate implies a plentiful supply of satellites on hand should they be needed.

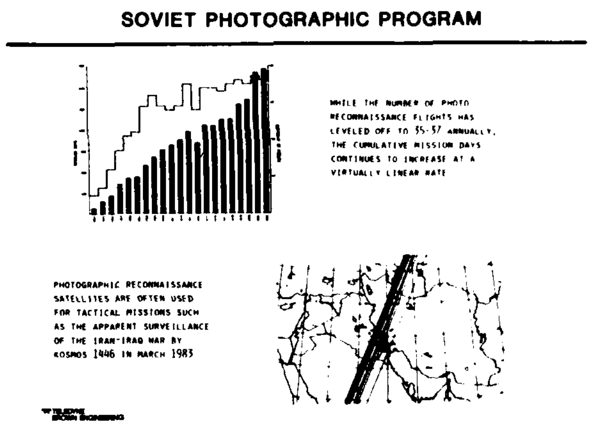


Figure 4: The Soviet photographic reconnaissance program is the largest space program in the world.

Soviet photographic spacecraft are often used to survey areas of international tension, such as the Middle East. In June and July 1982 three of the latest generation Soviet satellites maneuvered into positions highly suggestive of a monitoring mission during the conflict in Lebanon. Earlier this year Kosmos 1446 flew a highly unusual mission which permitted surveillance of the Iran-Iraq battleground during its entire two week flight.

In another field of space technology Soviet communications satellites are spread over four major constellations and number as many as 50 operational spacecraft (Figure 5). In the low altitude regime are two systems which are assumed

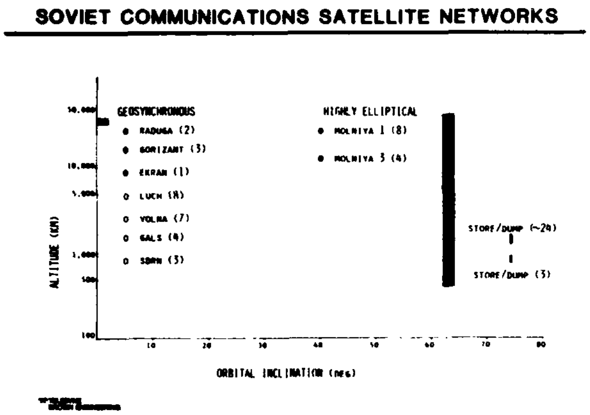


Figure 5: Soviet communications satellites are proliferated in widely varying orbits.

to fulfill military communications requirements in a store-dump mode. The first system consists of modest satellites (estimated mass, 750 kg) approximately 800 km high in three orbital planes spaced 120° apart. Command centers near Moscow or elsewhere in the Soviet Union can transmit to the satellites orders which are later replayed when the satellite passes over far-flung contingents.

A complementary system is comprised of many small satellites (∿40kg) orbited eight at a time to altitudes around 1470 km and with each launch entering the same nominal orbital plane. Considering the historical lifetimes of Soviet satellites, as many as 24 of these satellites may be operational simultaneously. Due to the orbital altitude and inclination of the satellites, Moscow should enjoy almost continuous contact with the constellation for 17 hours a day. This constellation is reminiscent of the U.S. Initial Defense Communication Satellite Program (IDCSP) which although utilizing much higher orbits relied on 26 operational satellites with a mass of 45 kg each.

The oldest Soviet communication satellite network is the Molniya system which still handles a large share of Soviet telecommunications. Placed in highly elliptical, 12-hour orbits, Molniya satellites are distributed in distinct groups. Eight Molniya 1 satellites are placed in orbital planes 45° apart in such a way that every satellite has identical groundtracks and are separated from one another in time by 3 hours. Four more advanced Molniya 3 satellites circle the Earth in orbital planes separated by 90° which are coincident with four of the Molniya 1 planes. Together the Molniya satellites provide domestic and international telephone, telegraph, and television services. Molniya 3 satellites also carry hotline communications between Moscow and Washington. Future Molniya satellites may carry Volna transponders for maritime and aeronautical users.

The Soviet Union was slow to exploit geostationary orbits for geographical, technological, and economic reasons. Since the first test flight in 1974 the Soviets have expanded their geostationary communications satellite program and now maintain seven geostationary positions. Three separate satellite systems are now operational: Raduga for domestic and international telecommunication, Gorizont for support of the INTERSPUTNIK network, and Ekran for television transmissions to Siberia, the Extreme North, and the Far East.

At least four more systems are due to be deployed during this decade. Luch, Volna, and Gals all appear to be special purpose transponders which will be attached to a mother satellite, possibly of a Raduga or Gorizont class. A Satellite Data Relay Network (SDRN) similar to the American TDRS system is also in the development stage.

The proliferation and diversity of Soviet communications satellites fit in well with the strong Soviet philosophy of survivable command, control, and communications (C^3). The more centralized control of Soviet satellites also implies a greater flexibility of communications links during periods of crisis or overt space hostilities.

In the matter of navigation satellites, the Soviets have taken a slow, low-risk approach. The first experimental navigation satellite was launched in 1967 and the first operational network was not completed until 1973. The interesting feature of these satellites is their remarkable similarity to the American Transit program whose first successful launch came in 1960. Not only are the polar, 1000 km high orbits of the Soviet system similar to those of Transit, but the doppler technique is virtually identical to that of Transit even down to the transmission frequencies. The current Soviet network is comprised of ten satellites divided into two constellations (Figure 6). The older six-member constellation appears to be devoted primarily to military users while the newer four-member group is available to civilians, particularly the merchant fleet. Like other Soviet satellite constellations, the capabilities of their navigation network are designed to degrade gracefully with the loss of one or a few satellites. On the other hand, the loss of one or two Transit

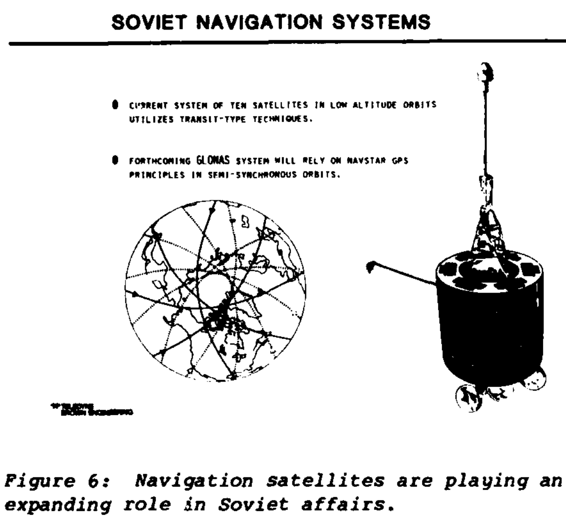


Figure 6: Navigation satellites are playing an expanding role in Soviet affairs.

satellites (out of a total of 5) would be more serious.

A new generation system is now under development in the Soviet Union, and it will be a clone of the American Navstar Global Positioning System (GPS). Dubbed the Global Navigation Satellite System (GLONASS), this new network will employ the same orbital parameters as the current GPS as well as almost identical transmission frequencies. The rationale behind copying American navigation techniques may lie in the potential of constructing receivers which operate on either the American or Soviet system. Since Transit and portions of GPS are available to civilians, the Soviets could use these satellites for non-critical missions.

Potentially, some of the most valuable Soviet satellites may belong to their ocean surveillance program. Regrettably these satellites usually only receive media attention when one of the nuclear-powered radar models malfunctions and falls back to Earth. Even then focus is not placed on their missions or capabilities, but instead of generating headlines about radioactive debris from space. By the end of 1982 two dozen spacecraft had been orbited in this radar ocean surveillance program since the first one appeared in late 1967. The program entered a new operational phase in 1974 when pairs of satellites (usually coplanar) began patrolling the world's oceans, searching for foreign naval vessels. Four such satellites were orbited in 1982. The third of these was the infamous Kosmos 1402, parts of which reentered the atmosphere in January and February of this year.

Also in 1974 a complementary program of passive ELINT ocean surveillance satellites was inaugurated. These satellites fly in slightly higher orbits, often in pairs, and are phased with satellites of the radar variety (Figure 7). Since 1980 operations of both types of satellites have greatly expanded.

SOVIET OCEAN SURVEILLANCE CONSTELLATIONS

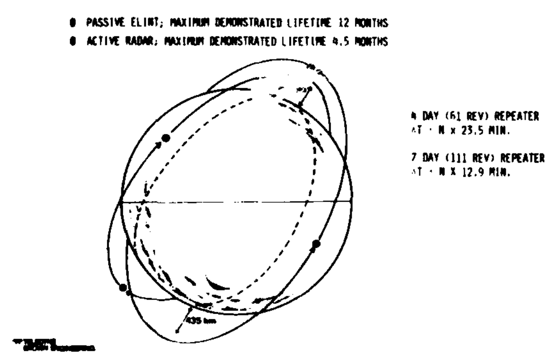


Figure 7: Ocean surveillance satellites are perhaps some of the USSR's most valuable space resources.

Reportedly, these satellites are capable of locating, tracking, and identifying enemy ships for targeting purposes. Replacements for malfunctioning satellites have been observed within 24 or 48 hours after mission termination. Replenishments are also sometimes timed to coincide with major Western naval exercises. For example, by early May 1983 all Soviet ocean surveillance satellites were non-operational. However, with large NATO sea games (Distant Drum '83) scheduled for 16-27 May, the first passive ELINT ocean surveillance satellite of the year was orbited on 7 May.

Another class of strategicly important satellites are those on missile early warning missions. Placed in orbits similar to Molniya satellites, the early warning spacecraft form a constellation capable of nearly world-wide surveillance. Again beginning in 1980, this network experienced a dramatic increase in Soviet attention and capabilities. The limited three-member network has been expanded to the full nine-member complement and the annual launch rate has more than doubled (Figure 8). In 1981-82 the entire constellation was shifted to provide better coverage of the United States. With perigees deep in the southern hemisphere, Soviet early warning satellites pose difficult targets for most anti-satellite systems.

SOVIET EARLY WARNING NETWORK

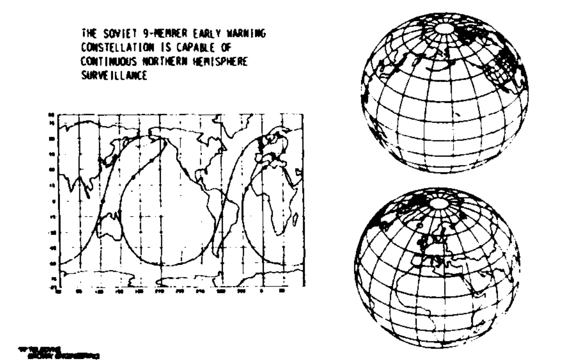


Figure 8: Since late 1980 the Soviet early warning netwoık has been expanded from 3 to 9 satellites.

The most significant development in the Soviet space program thus far in this decade has been the

Figure 9: The Soviet Union has twice space-tested a subscale model of a reuseable shuttle craft.

testing of a reuseable space plane. Flown once in 1982 and once earlier this year as a subscale model, the new spacecraft closely resembles the old NASA HL-10 lifting body. This picture (Figure 9) was taken by the Royal Australian Air Force during the recovery of Kosmos 1445 in the Indian Ocean on 16 March this year. The Department of Defense (DOD) estimates that operational, manned flights could come by the end of this decade. The space plane will probably be used as a shuttle craft for low altitude space stations, but could also play a reconnaissance role when necessary. A larger shuttle craft roughly equivalent to American STS shuttles is also apparently under development although the first test flight might be two or more years away.

Finally, we come to the only offensive space weapon system currently operational in the world: the Soviet anti-satellite (ASAT) system. Shown here in this DOD drawing (Figure 10), the Soviet ASAT vehicle is an orbital spacecraft which approaches close to its target and fires a conventional warhead. Between 1968 and 1982 the Soviets have tested this system twenty times. Successful intercepts have been made at altitudes as low as 150 km and as high as 1700 km. Times of flight vary from 1½ to 3½ hours.

Figure 10: The Soviet anti-satellite vehicle carries a conventional warhead.

The next illustration (Figure 11) depicts the intercept of a low altitude (230 km) target. The interceptor is launched into a longer, elliptical orbit and swoops down on the target from above. An alternate profile to attack higher satellites is shown here (Figure 12). The target is in a Transit-type orbit (i.e. 1000 km, circular). The ASAT spacecraft again enters an elliptical orbit, but this time the intercept is made from below at apogee. Although these two actual space tests required the interceptor to complete two revolutions of the Earth, successful tests have been made after only a single revolution. Consequently, warning time can be significantly reduced, placing a greater demand on the employment of countermeasures by the target.

The majority of tests during the past few years have concentrated on the perfection of a new optical or IR sensor for acquisition and end-game

SOVIET ANTI-SATELLITE TEST: 3 DECEMBER 1971

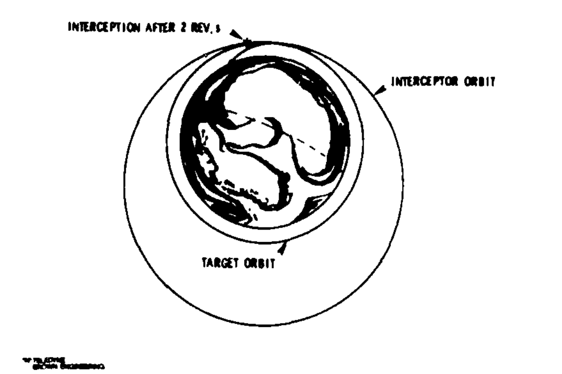


Figure 11: Satellites as low as 150 km have been intercepted by Soviet ASATs.

tracking of the target satellite. However, to date all such tests (a total of 6) appear to have been failures. The last successful ASAT test was in March 1981 when an older, radar-guided ASAT was used. If both types of ASAT become operational American countermeasures may have to be more versatile.

SOVIET ANTI-SATELLITE TEST: 14 MARCH 1981

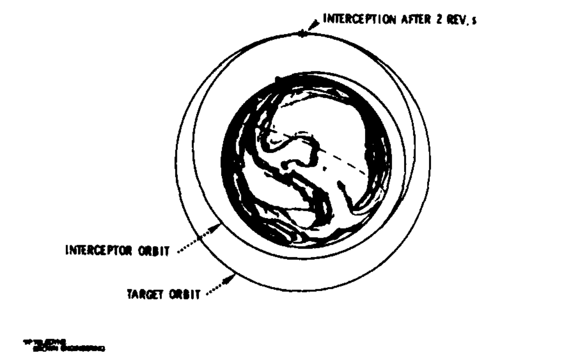
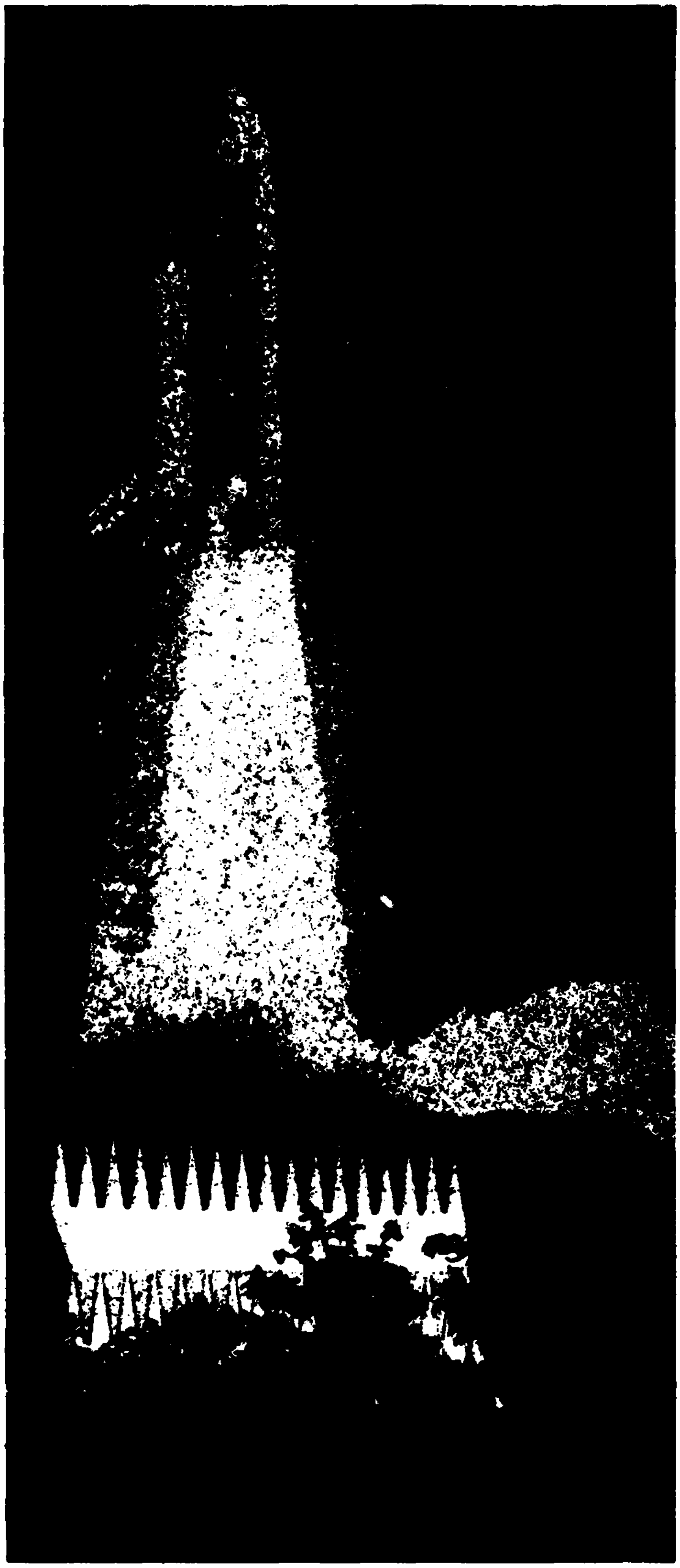


Figure 12: Soviet ASATs can probably reach targets as high as 2000 km.

Since the majority of American satellites are in high altitude orbits, they are now beyond the reach of the Soviet ASAT. In 1981 DOD speculated that the Soviets were then working on a new system which could attack synchronous and semi-synchronous satellites. This could be accomplished by mating the current ASAT with a larger launch vehicle (eg. SL-12) or by designing an entirely new, multi-shot ASAT. Meanwhile some highly valuable, low altitude American satellites remain vulnerable to Soviet attack.

The combination of proliferated support satellites and their ready replacements with an anti-satellite capability presently gives the Soviets a war-fighting edge should hostilities leap from the surface of the Earth into outer space. Failure of the United States to address this disparity of space forces will have far-reaching consequences in both global military and political affairs.



Session 7

Simulation and Testing

Session Chairman: J. E. Maxwell, *TRW*

The Papers

Invited Paper—DSCS III: Acquisition and Testing

Invited Paper—Distributed Database Performance Modeling

Optimization of Satellite Orbital Parameters for Oceanic Surveillance

Dynamic Spacecraft Simulators in Military Space Ground Systems

DSCS III: ACQUISITION AND TESTING

COLONEL GARY CULP

DEPUTY FOR DEFENSE SATELLITE COMMUNICATIONS SYSTEM

AIR FORCE SPACE DIVISION

LOS ANGELES, CALIFORNIA

ABSTRACT

The Defense Satellite Communications System Phase III (DSCS III) satellites will provide key capabilities for the DSCS space segment in the 1980's and 1990's. Acquisition strategy for these third generation DSCS spacecraft will be outlined, beginning with competition for full-scale development and through the planned procurement of at least twelve follow-on production satellites. Special testing performed to help determine system survivability/nuclear hardness will be reviewed. Planning and execution of launch operations and orbital testing of the first development satellite will be discussed, including Initial Joint Operational Test and Evaluation. Operational deployment and user plans will also be highlighted to include current satellite location and coverage.

AD P002157

DISTRIBUTED DATABASE PERFORMANCE MODELING

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ABSTRACT

This paper describes a distributed database model that simulates database utilization in the SPADOC data processing environment. The model is table driven such that database access requirements, file locations, and other information necessary for defining the database environment are set up internally in several tables. Each operation for the SPADOC mission is defined and represented by a transaction flow diagram (TFD) and a sequence of TFDs representing a mission is input to the model. The model executes input TFDS by looking up tables that specify their data file access requirements. While executing TFDs, the history of database usage is logged and various statistics are gathered. The performance data are used to measure database access overhead, characterize database workload, and fine-tune performance by reallocating files.

The model has been implemented in Fortran on the VAX 11/780 and has been used for both measuring a given database and analyzing sensitivity to design changes. It has proven to be an effective tool for measuring and analyzing design effectiveness of distributed databases.

INTRODUCTION

This paper describes a simulation and analysis method that was used to model the distributed database usage pattern of the Space Defense Operation Center (SPADOC) which is to be deployed by NORAD. The simulation deals primarily with file access behavior of a subject system and does not simulate details of database management functions such as query processing and database methods. It represents or assumes no specific database management system, and hence, no provisions are made for such complex design issues as concurrency control, replicated file update, failure recovery, and the like, which are subjects of current intensive research. Although the simulation model was developed for a special case of distributed databases, it is applicable to a wide variety of distributed database designs.

The literature on distributed database simulation is scarce, if any, possibly because most simulation experiments are application-specific and because only a small number of distributed databases have been implemented. Development of distributed databases involves a number of problems that defy simple solutions (1). Furthermore, in most cases, database performance is measured by benchmarking rather than simulation (2, 3). However, benchmarking must have available a database and workload that are representative of the application environment. Simulation of a distributed database is often done analytically (4, 5), but analytical simulation lacks fidelity of database representation and is usually used for modeling a top level structure of database systems.

In the sections that follow, the SPADOC operational environment and database design are summarized. The database usage simulation model organization and simulation method are presented and example results are analyzed.

SPADOC OPERATIONAL ENVIRONMENT

SPADOC is a command and control system for the Air Force/NORAD space defense missions. The SPADOC will catalog orbital characteristics of all space traffic, maintain space asset status, access the space situations and issue warnings of hostile actions, protect space assets from the hostile actions, and if necessary, coordinate negation activities of hostile threats to space assets. SPADOC is an evolutionary system and will be developed over the next several years to meet future Space Command mission needs.

The current design for the SPADOC baseline hardware architecture consists of three IBM 3083s connected by a high-speed bus: two operationally active and one a backup (Figure 1). Although

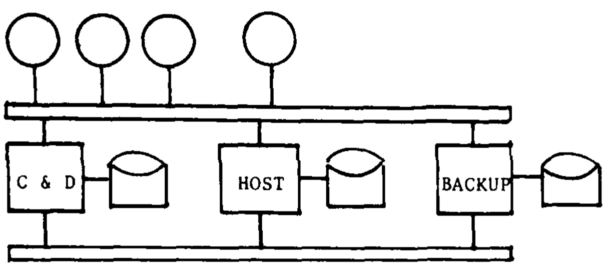

Figure 1. SPADOC Baseline Hardware Configuration

physically similar, all three computers have distinct functions and interact with each other over the high speed bus. The Communications and Display (C&D) computer processes operator commands and requests, and provides sophisticated display output (e.g., graphics) and serves as the communication processor to interface the automatic message handling system software. The Host computer executes all computationally complex application programs; i.e., programs necessary for satellite tracking and space situation assessment. The backup processor is normally used for exercise and training, but in case of failure, can be switched on-line to replace a failed operational computer. All three computers contain network database management systems (DBMSs). This hardware redundancy improves significantly the availability/reliability of the distributed system (6). Redundancy is also provided for the disk storage so that critical and frequently used files may be duplicated.

The SPADOC data processing is characterized by heavy interactions between the operator and the database system and between application programs and the database system. It will eventually evolve such that most of the operator intervention will be automated so that manual operations are minimized. Our analysis shows that approximately 90 percent of all accesses to the database are due to applications programs, suggesting that the database efficiency is crucial to the overall system performance. This necessitated a rigorous analysis of the database performance and access patterns.

SPADOC DATABASE DESIGN

The SPADOC database is partitioned without replication between the host and C&D (Figure 1) eliminating the need for updating multiple copies. Each processor has a complete database manager and when necessary, is able to access the other database partition transparent to the requester through the connecting bus. Files are allocated such that a processor accesses the local database almost exclusively. This minimizes communication overhead incurred in database access. Database partitioning has several advantages with respect to performance, growth potential and reliability; these include:

1. Data access time is reduced significantly because each partition is physically much smaller than the total database;

2. Throughput of database processing is increased because database accesses may be processed concurrently at multiple processors;

3. Potential for database access contention is reduced because access is made at different partitions;

4. Potential for creating a system bottleneck to request queue buildup is minimized by database load balancing;

5. Failure of one computer results in loss of partial database only;

6. Fault recovery is done much faster because each partition is physically smaller and the number of updates journaled during failure should be smaller;

7. Additional processors and database partitions may be added to accommodate growth without disturbing the existing ones.

To be sure, database partitioning has some drawbacks. Most notably, the design complexity requires careful analysis for file allocation (7). If file allocation was done improperly, the database performance degrades rapidly.

SIMULATOR DESCRIPTION

The simulator is a table-driven model that represents the database environment and simulates database usage of a SPADOC mission. A SPADOC mission is represented by a sequence of transaction flows called TFDS (Transaction F ow Diagrams). A TFD is a control flow diagram t onsists of flows of control, operator tran tions, program module executions and files acc d (Figure 2).

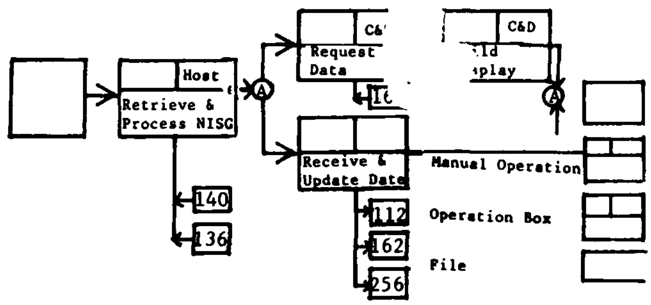

Figure 2. Example TFD

A TFD defines an operation such as threat assessment and verification, vulnerability to nuclear effects, cluster analysis, etc. A mission is generated by the Scenario Generator which is an interactive tool for the design, simulation and analysis of space defense scenarios. For a user supplied description of the space engagements to be modeled, the Scenario Generator generates a timeline of mission events including launches, manuevers, intercepts, etc., which is used to activate the SPADOC TFDs and in turn drive the database model as well as the data processing simulation model.

The database usage simulator consists basically of three units: initialization unit, mission execution unit, and report generation unit. The initialization unit prepares all the data and tables necessary for the simulation. In particular, it constructs three tables that represent the file access patterns of TFDs (Figure 3). A mission tape generated by the Scenario Generator is input to the database simulator. All TFDs to be executed are represented by a number which is used as an index to a table, TFDKEY, that contains indices to another table, INVOKE. A pair of consecutive

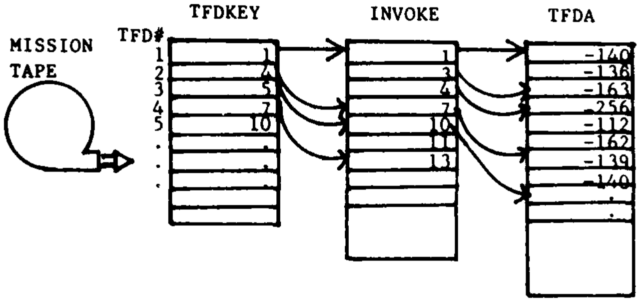

Figure 3. Table Structure for TFD File Access Representation

elements in TFDKEY specify the operation boxes within one TFD. A pair of consecutive elements in INVOKE specify a list of files to be accessed by an operation box. The contents of the three tables for the example TFD are shown in Figure 3. A negative file number in TFDFA denotes write access to the file.

The report generator unit receives data provided by the mission execution unit and generates comprehensive reports that summarize the result of simulation.

The mission execution unit performs the simulation proper. During simulation, it collects data and generates performance statistics. Logically, it consists of four program modules:

1. File Access Simulator. By table look-ups, this executes database accesses for TFDs, determines types of access such as local/remote and read/write, and gathers statistics on file usage. Some typical statistics include a number of local read and local write accesses, remote read and remote write accesses, sources of access, etc.

2. Buffer Manager. For each file access, this determines whether the requested file is in the work area (i.e., buffer) and counts the number of time the files are found in the work area. This number is used to compute the hit/miss ratio and the amount of overhead necessary for disk storage access.

3. File Access Correlator. This analyzes the situation where two or more files are accessed. In many instances, whenever one file is accessed, another file is also accessed. These files are correlated so that some optimization in file structure and file allocation may be made.

4. Histogram Generator. This generates a histogram of database workload during an entire mission. This histogram may be constructed at any pre-specified interval. This was used to identify a peak load period so that more detailed performance analysis may be done for this period.

Figure 4 shows the structure and interrelation of the software components discussed above. The File Access Correlator and Histogram Generator may be switched on or off by setting appropriate flags. The program is written in Fortran 77 on the VAX 11/780 and is relatively small (approximately 600 source lines) and modular.

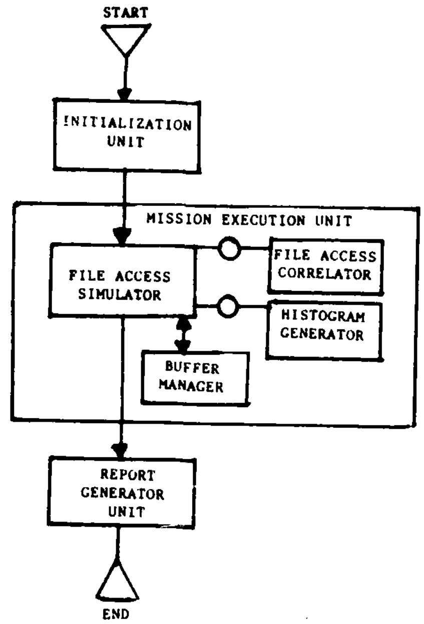

Figure 4. Structure of the Database Usage Simulator

ANALYSIS OF RESULTS

Examples of the simulator outputs are illustrated in Figures 5-8. Figure 5 shows summary results of file usage during a hypothetical mission which spanned 67 hours, 27 minutes. During this mission period, a total of 4908 file accesses were made, of which 4137 (84 percent) were read access and 771 (16 percent) write access. The frequencies of access to the host and C&D databases as well as the sources of the accesses are also shown. Occasionally, a computer (or the operator) needs access to data located at the other computer requiring request message transmission across the connecting bus. This database access across the bus is called a remote access. A remote access is extremely time and resource consuming so that it should be minimized where possible by strategically allocating the files at either the host or C&D. In this example, slightly over 10 percent of all accesses are remotely made. To minimize the remote access rate, the access profile of each individual file must be analyzed so that a better file allocation may be determined (7-9). Figure 6 shows individual file usage profiles which list sources and types of access and their frequencies. Of particular interest for allocation are columns for remote use (read) and remote set (write). If a file is more frequently remote-accessed than local-accessed, it is a good candidate for reallocation. In addition, prioritization of read/write access types can also factor into tuning the database allocation, e.g., often read accesses are considered more critical than write accesses.

DB Work Area (Buffer) Size for Host:	20 Files	
DB Work Area (Buffer) Size for C&D:	20 Files	
Total Number of TFD's Executed	= 438	
Elapsed Mission Time	= 67 Hours 27 Min 1 Sec	
Total Number of File Accesses	= 4908	
Number of Use (Read)	= 4137	(84.29 Percent)
Number of Set (Write)	= 771	(15.71 Percent)
Number of Accesses to Host DB	= 2347	(47.82 Percent)
From Host	= 2073	(88.33 Percent)
From C&D	= 96	(4.09 Percent)
From Operator	= 178	(7.58 Percent)
Number of Hits at Host	= 1314	(55.99 Percent)
Use = 1110 Set	= 204	
Number of Accesses to C&D DB	= 2561	(57.18 Percent)
From Host	= 236	(9.22 Percent)
From C&D	= 2179	(85.08 Percent)
From Operator	= 116	(5.70 Percent)
Number of Hits at C&D	= 2220	(86.68 Percent)
Use = 1884 Set	= 336	
Total Number of Remote Accesses	= 510	(10.39 Percent)
Remote Accesses to Host	= 274	(5.58 Percent)
Remote Accesses to C&D	= 236	(4.81 Percent)

Figure 5. Summary of File Usage Statistics

FILE ACCESS PROFILE

File No	File Loc	Transaction Source: Host AP	C&D AP	C&D OP	Transaction Types: Local Use	Local Set	Remote Use	Remote Set
101	C&D	0	147	0	147	0	0	0
102	HST	25	0	0	25	0	0	0
103	HST	0	0	0	0	0	0	0
104	C&D	0	147	0	147	0	0	0
105	C&D	31	147	0	147	0	0	31
106	C&D	13	147	0	147	0	0	13
107	HST	31	0	0	0	31	31	0
108	C&D	0	147	0	147	0	0	0
109	C&D	0	147	0	147	0	0	0
110	C&D	0	147	0	147	0	0	0
111	C&D	0	3	0	1	2	0	0
112	C&D	1	26	0	0	26	0	1
113	C&D	0	147	0	147	0	0	0
114	HST	0	0	0	0	0	0	0
115	HST	31	0	0	31	0	0	0
116	HST	13	0	0	13	0	0	0
118	HST	0	0	0	0	0	0	0
119	C&D	0	0	0	0	0	0	0
121	HST	71	0	0	71	0	0	0
122	C&D	0	147	0	147	0	0	0
123	HST	78	0	0	52	26	0	0
124	C&D	0	0	0	0	0	0	0
125	C&D	26	26	0	26	0	26	0
126	HST	31	0	0	31	0	0	0
127	HST	26	0	0	26	0	0	0
396	C&D	0	0	0	0	0	0	0
398	C&D	0	0	0	0	0	0	0

Number of Files at Host = 76
Number of Files at C&D = 97

Figure 6. Access Profile of Individual Files

Figure 7 illustrates the database workload characterization over a mission period. In this example, all database accesses in five minute periods are distinguished for the host database and C&D database accesses as well as local/remote read and local/remote write. This data is useful for identifying a five minute peak load period and observing the distribution of workload between the host and C&D during this period. If one of the computers is overloaded, for example, and could not meet the performance (e.g., response time) requirement during this critical peak load period, load balancing based on these data can be performed.

DATA BASE WORKLOAD DISTRIBUTION

Time	Freq	Transaction Source: Host AP	AP	OP	Local Use	Remote Use	Local Set	Remote Set	Local Use	Remote Use	Local Set	Remote Set
23: 2: 0	43	3	40	0	2	1	1	0	35	0	4	0
23: 7: 0	32	14	20	1	10	1	2	0	16		5	0
23:12: 0	52	7	44	1	5	2	2	0	38	0	4	1
23:17: 0	20	4	14	1	5	1	1	0	13	0	2	0
23:22: 0	21	14	6	1	10	2	5	0	5	2	1	0
23:27: 0	8	6	2	1	4	0	1	0	2	0	1	0
23:32: 0	9	6	1	1	4	0	1	0	7	1	1	0
23:37: 0	7	7	1	1	5	0	1	0	1	0	0	0
23:42: 0	20	6	14	0	5	0	1	0	12	1	1	0
23:47: 0	5	1	1	0	1	1	1	0	1	1	0	0
23:52: 0	1	1	0	0	1	0	0	0	0	0	0	0
23:57: 0	0	1	0	0	0	0	0	0	0	0	0	0
24: 2: 0	12	0	12	0	0	0	0	0	11	0	1	0
24: 7: 0	19	17	3	0	12	0	5	0	3	1	0	0
24:12: 0	19	5	13	0	4	0	1	0	12	1	1	0
24:17: 0	0	0	0	0	0	0	0	0	0	0	0	0
24:22: 0	23	5	18	0	4	0	1	0	17	0	1	0
24:27: 0	23	14	9	0	11	0	2	0	7	0	2	1
24:32: 0	70	28	42	0	22	0	4	0	37	0	5	2
24:37: 0	87	24	63	0	11	0	11	0	57	1	6	1
24:42: 0	75	32	43	0	26	0	4	0	37	0	6	2
24:47: 0	91	26	66	0	20	0	3	0	59	0	7	2
24:52: 0	49	21	29	0	17	0	3	0	25	0	3	1
24:57: 0	82	37	45	0	29	0	5	0	39	0	6	1
25: 2: 0	88	14	74	0	11	0	2	0	67	0	7	1
25: 7: 0	52	35	22	0	27	0	3	0	16	0	4	2
25:12: 0	72	43	26	1	26	0	13	0	24	1	4	2
25:17: 0	61	7	50	1	8	0	0	0	47	0	5	1
25:22: 0	28	1	25	1	1	0	0	0	23	0	4	0
25:27: 0	39	2	36	1	1	0	0	0	34	0	4	0
25:32: 0	26	2	24	1	1	0	0	0	23	0	2	0
25:37: 0	61	1	60	1	1	0	0	0	55	0	4	1
24:42: 0	11	1	11	0	1	0	0	0	9	0	1	0
25:47: 0	3	1	2	1	1	0	0	0	0	0	2	0
25:52: 0	3	1	2	1	1	0	0	0	0	0	2	0
25:57: 0	7	1	1	1	1	1	1	0	2	1	1	0
26: 2: 0	3	1	0	1	1	0	0	0	1	0	1	0
26: 7: 0	0	1	0	1	0	0	0	0	0	0	0	0
26:12: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:17: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:22: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:27: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:32: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:37: 0	0	0	0	0	0	0	0	0	0	0	0	0
26:42: 0	3	3	1	0	3	0	0	0		0	0	0
26:47: 0	34	9	25	0	8	0	1	0	23	0	2	0
26:52: 0	8	4	1	2	2	0	1	0	3	3	1	1
26:57: 0	11	1	7	2	1	0	0	0	8	0	2	0
27: 2: 0	8	1	7	1	1	0	0	0	5	1	2	0
27: 7: 0	8	6	2	0	4	1	1	0	1	1	0	0
27:12: 0	0	0	0	0	0	0	0	0	0	0	0	0
27:17: 0	0	0	0	0	0	0	0	0	0	0	0	0
27:22: 0	0	0	0	0	0	0	0	0	0	0	0	0

Column groups printed above the header: Host Data Base; C&D Data Base.

Figure 7. Data Base Workload Distribution Over Mission Time

File access correlation expressed in frequency of concurrent access to file clusters is shown in Figure 8. In the example, files 121 and 106, 116 and 149 are accessed together 13 times. Correlation is useful for both file allocation and physical organization and indexing of files.

File Numbers												
	133	155										
111	1	1										
	162	121										
112	26	1										
	105	121	148	152	157							
115	31	31	31	31	31							
	106	121	149	152	157							
116	13	13	13	13	2							
	106	116	149	152	123	161	171	105	115	148	157	112
121	13	13	13	70	26	26	26	31	31	31	31	1
	101	104	105	106	108	109	110	113	164			
122	147	147	147	147	147	147	147	147	147			
	125	127	152	121	161	171						
123	26	26	52	26	52	26						

Figure 8. File Access Correlation

CONCLUSIONS AND FUTURE EXTENSIONS

A simple, yet effective distributed database simulation model is presented. Generally, simulation of a fully distributed database is extremely difficult because of a number of unknown factors that exist in the design. The SPADOC database, however, is distributed without replication between two processors, which simplified considerably many of the problems associated with the design and made the simulation more tractable. Although developed for a specific database, the simulation model and method are applicable to more general, more complex distributed databases.

The simulation model is being refined to implement simulation of database access contention so that overhead in concurrency control may be calculated. Database access overhead that includes disk storage access is being incorporated. However, overhead calculation is to a great extent dependent on a particular database management policy and access time of particular disk storage devices. The simulation must be flexible enough to model a variety of database managers so that comparative database performance analysis may be made.

The database simulation model has been used extensively as a design tool for the SPADOC database design and has proven to be very valuable. It was used to analyze sensitivity to database design and operational environment changes. As demonstrated by the examples, the database usage data generated by the simulator provided the basis for effective database design performance measurement and validation.

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OPTIMIZATION OF SATELLITE ORBITAL PARAMETERS FOR OCEANIC SURVEILLANCE

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ABSTRACT

This paper examines the tradeoffs in orbital parameters and the geometric relationships involved in satellite surveillance of ocean areas. For illustrative purposes synthetic aperture radar (SAR) has been used as the sensor, hence some discussion of the sensor characteristics is included as well as orbital considerations, power requirements and data processing. Assuming that a target is detectable with SAR, this paper concludes that a single SAR satellite with optimum orbital parameters provides a high probability of detection of a target transitting in a given coverage area.

PART I - INTRODUCTION

Background

1. Submarine detection since the World War II has been largely dependent on acoustic means. While passive devices have increasingly replaced active sonar both are inherently limited by the vagaries of sound propagation in water. The search for reliable large area, non-acoustic means of detection has been unsuccessful but attempts continue.

2. The effects such a sensor, mounted on a satellite, could have on maritime operations would be dramatic. They prompted Admiral Rickover, in Feb 82, to state "The future naval war is going to be decided under the polar ice - the only place submarines will be able to hide from satellites."

Aim

3. The aim of this paper is to examine the tradeoffs in orbital parameters and the geometric relationships involved in satellite surveillance of submarines, given that a suitable sensor were available.

PART II - DISCUSSION

Approach

4. Synthetic aperture radar (SAR) will be used as the illustrative sensor, hence a discussion of its characteristics is included. These characteristics are compared to orbital parameters to derive general guidelines for orbit construction. An initial orbit is developed and its coverage, advantages and disadvantages are discussed. Next communications, data processing and power considerations for a satellite-borne SAR are dealt with. Detection probabilities of this orbit against a specific submarine mission are evaluated, first using one satellite, then a two satellite constellation. Based on this orbit's disadvantages, an improved one is constructed and evaluated in the same way as the first. Lastly general conclusions about orbital and operational requirements are formulated.

Synthetic Aperture Radar

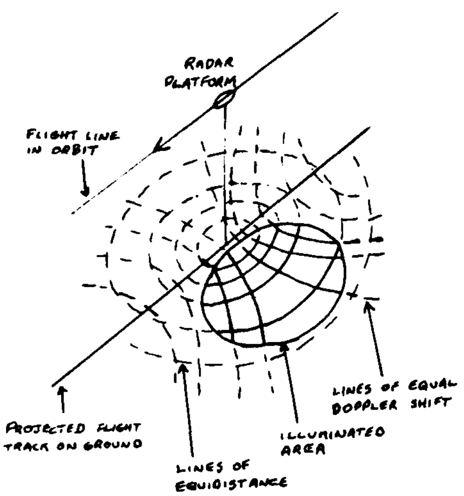
5. A conventional all-around search radar scans in azimuth by a continuous 360 degree rotation of the antenna. It's resolution in range is dependent on the duration of the transmitted pulse and is independent of range. In azimuth, resolution is dependent on beamwidth. For a given frequency the larger the antenna the narrower the beamwidth. Since the beam gets wider with increasing range the resolution decreases with range ie at twice the range the azimuth resolution is only half as good.

6. Operation. In a Synthetic aperture radar the antenna is fixed and points off the direction of motion, most often by 90 degrees. The azimuthal extent of the scene viewed by the radar is established by the movement of the radar platform carrying the radar footprint over some

particular distance by collating together the successive radar returns received during the time period the radar platform was carried over that distance. As in a conventional radar a SAR transmits a microwave pulse which strikes the area of interest and returns to the receiver. Range is determined in the normal way by the time it takes the pulse to travel to and from the target. In a SAR however the frequency spectrum of the returned pulse is also determined. By comparing this to the frequency of the transmitted pulse the changes in frequency due to the doppler caused by satellite motion are known. As will be shown, in effect this causes the azimuthal resolution to be a function of the data processing carried out.

7. In fig I the footprint of the radar beam for a single pulse is shown. The concentric rings centered on the satellite sub-orbital point (position on the earth directly beneath the satellite) are lines of equal range. The hyperbolas show lines of equal doppler shift. Thus a given range and a given doppler shift will uniquely define a point on the earth's surface. However from a single radar pulse we cannot determine how much of the energy in the returned signal is due to that point alone. If we illuminate the point with a succession of pulses (several thousand) over several seconds from a transmitter moving at high speed it is possible to extract that information by evaluating the way in which the range and the doppler shifts vary over the time interval chosen.

FIG I - SAR OPERATION



8. <u>Resolution</u>. Extensive data processing of the "film strip" raw data from a synthetic aperture radar produces an image resembling a strip photograph depicting an area up to several hundred nautical miles wide. The resolution in range (ie, across the width of the strip) is dependent on the transmitted pulse duration as in a conventional radar. The resolution in azimuth (ie along the length of the strip) is, in practice, dependent on how small a doppler shift we can detect and is independent of the range to the target. It is therefore a function of the duration of the period over which the raw data is integrated and thus to the power of the processing applied to the data.

9. Since it operates in the microwave region SAR is, unlike a camera, essentially independent of weather and lighting conditions. Being a line-of-sight device the higher it is above the ground the greater area it has in view.

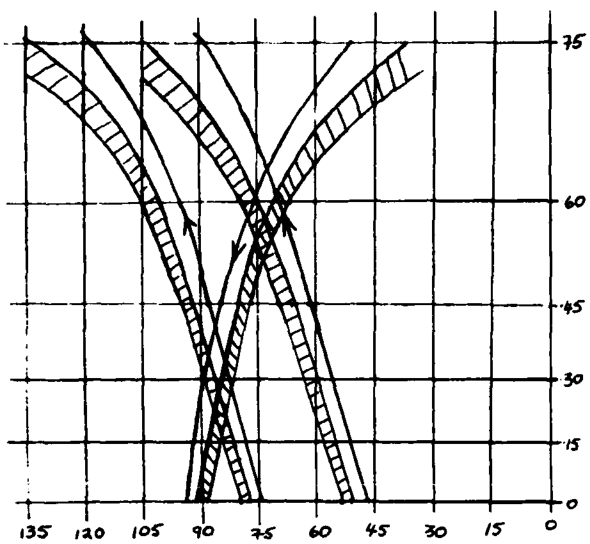
10. SAR is inherently useful only against stationary or slow moving targets since its resolution depends on the use of the frequency change (doppler) of the returned signals, and the data processing makes the assumption that the doppler is contributed (caused) only by the motion of the satellite, and by the rotation of the earth, not by target movement.

11. <u>Past Use</u>. Synthetic aperture radar has been used for a number of years mounted on aircraft but only recently have the obvious potential advantages of placing it at a much higher altitude (i.e. on a satellite) been utilized. Thus far its use on satellites has only been experimental (SEASAT in 1978 and Shuttle 2 in 1981) but there are several projects ongoing in Canada, Europe and Japan to use it commercially for ice reconnaissance, surveillance of crop conditions and other resource related activities. These projects have anticipated launches in the period 1988-1990.

Orbital Considerations

12. None of the above mentioned projects are optimized for open ocean coverage. As a result their coverage tends to overlap or leave areas un-looked at. The coverage pattern of the proposed Canadian project (called RadarSat) is shown in Fig 2 as an example of this. The reason for this uneven coverage is that the ascending and descending swaths cross at a significant angle.

FIG 2 - RADARSAT COVERAGE PATTERN



13. Inclination. To minimize the amount of duplicated coverage an orbit whose coverage swath runs as near as possible along a meridian (i.e. N-S) is required. For the altitude of interest (550-650 nm) this requires an inclination in the order of 84 degrees.

14. The coverage obtained is a swath whose inside edge is offset, in this design, to the left of the sub orbital point by some 180 nm and it is 307 nm wide. This is the area that can be covered. The actual coverage on any one pass is less and varies slightly (decreasing with distance from the sub orbital point) but averages 155 nm. Thus one of the prime considerations is which part of the "potential" coverage area will actually be looked at on a given pass. For the sake of simplicity we will initially assume that all passes are looking at the area closest to the sub-orbital point.

15. In order to examine the factors important to submarine surveillance it was necessary to define the submarine's important operating parameters. A submerged transit from North Cape to 53N 22W at a speed of approximately 5 knots was selected as the intended target. 40 degrees N latitude was arbitrarily selected as the southern limit of the coverage area principally because this appeared to include the major areas of surveillance interest while still being possible to cover in a useful number of days. At 40N the edges of the swath are nearly N-S but they "spread" to encompass a greater number of degrees of longitude as the latitude increases. For the descending pass the area of coverage is a mirror image of this. The next step was to build up a pattern of these swaths which gave complete coverage of the area N of 40N in the minimum number of days.

16. Altitude. For the altitude of interest we have a period in the order of 110 min which means approximately 13 ascending and 13 descending passes per day. If the altitude is decreased slightly thereby decreasing the period, the 14th pass is slightly East of the first one because the earth has rotated somewhat less than 360 degrees since less than a day has elapsed. Similarily if the altitude is increased, the period increases and the fourteenth pass is slightly West of the first because more than a day has elapsed.

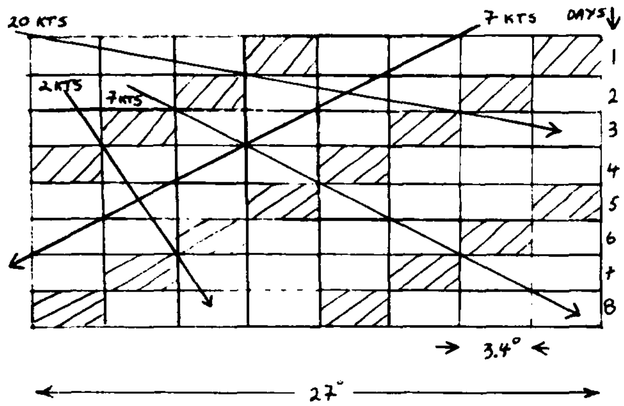
17. Thus the altitude affects both the pattern of the ascending and descending passes and at what rate the pattern shifts East or West each day. Since our inclination has been determined by the desired swath geometry the altitude is the only remaining parameter we may adjust to satisfy these two independant requirements.

600 NM Orbit

18. Swath pattern. One possible altitude for this situation turns out to be approx 600 nm. At this altitude each descending pass is centered between adjacent ascending passes. The separation between centres of the ascending passes is approximately 27 degrees and between adjacent ascending & descending passes approximately 13.5 degrees.

19. Swath rotation. This altitude also causes the pattern to shift some 10.2 degrees East per day. Thus on day 2 each ascending pass has shifted so that it is immediately adjacent to the previous days descending pass. The easiest way to visualize this is to imagine a pattern of 26 spokes spaced 13.5 degrees apart radiating outwards from the North Pole. For this case the net effect is to make it appear as if the 26 spokes are rotating westward at approximately 3.4 degrees/day. At the end of 4 days every point N of 40N has been viewed at least once. The pattern of coverage buildup is identical in each 27 degree sector and is depicted for one sector only in fig 3.

FIG 3
600 NMI ORBIT - 1 SAT ACTUAL COVERAGE



20. This spoke analogy holds true for any surveillance satellite whose sensor views a swath of limited width and whose inclination is near to 90 degrees. The number of spokes, their width and the rate at which they rotate will vary with the sensor type and the satellite's altitude but the basic characteristics are the same. Continuing this analogy, the areas between the spokes, which are not covered, are "blind spots" and any moving target that stays between spokes will remain undetected. Since the spokes rotate at a constant angular velocity (in this case 3.4 degrees/day) the actual speed required to stay in a blind spot will vary - increasing with decreasing latitude. As will be shown shortly the rotation rate of the pattern of spokes is very significant for the purposes of this paper.

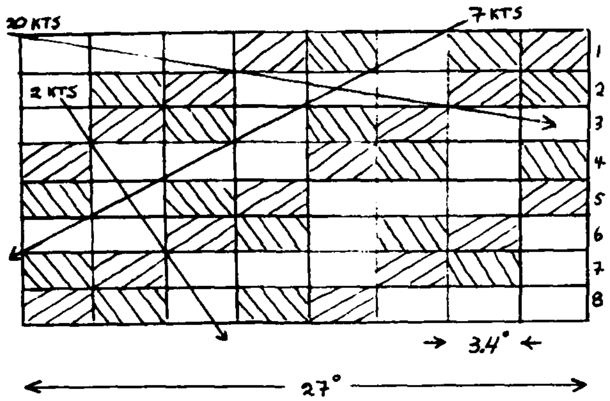
21. Latitude effects. Since each swath covers a constant width on the ground, it views an increasing number of degrees of longitude as its latitude increases. Since it is possible to steer each swath within the total potential coverage area of that pass, there comes a latitude when it is possible to cover the entire 27 degrees with only 6 swaths; i.e. in only 3 days. Similarily there is a latitude where complete coverage is possible every two days. For this 600 nm orbit three day coverage is possible N of 56 degrees N & two day coverage N of 68 degrees N.

22. SAR output. Thus with this one satellite all open ocean north of 40N would be viewed every 4 days, north of 56N every 3 days and north of 68N every 2 days. Further we will get an approximate size of surface vessels and their course. It is also possible to get an approximation of surface vessels' speed. As was mentioned earlier data processing assumes that none of the relative motion between radar and target is caused by the target. Thus any velocity of the target radial to the radar introduces an additional doppler signal which the processor (falsely) interprets as a shift in position of the target. Since the wake is stationary it is not offset. Knowing the heading of the satellite and ship and with the measured offset of the ship from its wake it is possible to determine ship's speed. Finally there is some promise that imaging (identification) on a non-cooperative basis of ships down to type and class may be possible using SAR.

23. Orbital disadvantages. The largest disadvantage to this orbit is the regularity and slowness with which the coverage pattern (and therefore the "blind spots" between spokes) rotate westward. Fig 3 depicts time in days on the vertical scale versus longitude for one 27 degree sector at 40N. The shaded areas are the indicated width of longitude covered on a given day. If the target maintains a speed of approximately seven knots (one swath width per day) in a westerly direction it can remain undetected indefinitely. Undetected movement in an easterly direction is also simple and the permissible speeds more varied, including 2, 7 and 20 knots.

24. Swath switching. Up to this point we have assumed that the radar beam was fixed on the coverage area nearest the sub-orbital point. In fact it is steerable and using this we can improve the chances of detection by having the radar look at either the near half or the far half of the "potential" coverage area on a random basis. Figure 4 shows the possible coverage area versus time. Every time a target crosses one of these shaded areas it has a .5 probability of being detected. With this random switching of swaths a given point may not be viewed for longer than the nominal frequency of coverage but as a target crosses the "possible" area more than once his probability of remaining undetected falls rapidly.

FIG 4
600 NMI ORBIT - 1 SAT POTENTIAL COVERAGE



25. Note that it is still possible to transit in a westerly direction undetected at 7 knots but more precise speed & navigation requirements are imposed. The effect on easterly movement is similar. These coverage characteristics are for latitude 40N but the salient points remain unchanged up to latitude 56N at which point the "spreading" of the swaths gives an overlap of the possible coverage areas making assured undetected movement *impossible*. The best route to avoid detection is the same but the probability of detection is now .5 every two days. (ie the target must cross a possible coverage area once every two days).

26. Thus the coverage provided by this orbit, while imposing restrictions on a target's movement and limiting his tactical freedom, can be evaded at lower latitudes.

27. Tracking. Once a target was detected and if there was a requirement for increased surveillance this could be accomplished by having every satellite pass within range adjust it's swath to cover the expected position of the target. Unfortunately the time of the next available pass is very dependant on the targets position within the pattern varying from 12 to 108 hours later. This would make the quality of tracking extremely unpredictable.

Data Processing and Communications.

28. A SAR generates very high data rates; in the order of 120 million bits/sec. Up to the present all of the processing for SARs has been done on the ground in non-real time. Any system for ocean surveillance would have to be real time to be of operational use due to the highly perishable nature of the information. To illustrate consider a submarine target with a speed of five knots. If we wish to localize using a maritime patrol aircraft we have to bear in mind that the MPA's typical search area resembles a rectangle, 60 NM wide and 120 NM long. If the target makes a radical course alteration after detection he could be out of the aircraft's search area in six hours. Even if he took no evasive action he would be out of the search area in 12 hours. By this time the SAR information has lost much of its tactical value.

29. Processing. Given that real time processing is required there is an inherent tradeoff between the amount of processing done on the satellite and the bandwidth (plus complexity) required of the satellite's communication system. Any processing done on the satellite would reduce the demands on the communications system (i.e. lighter, less expensive, lower power, fewer spectrum management problems). Against this is balanced the weight of the on-board processor, which at present is prohibitive, as well as the risks involved in an untended processor and the difficulties in splitting up the processing sequence. There is also the question of flexibility (i.e. will we wish to change the processing algorithm?) and susceptibility to seduction (enemy capture of the satellite control and its on-board functions). These are some of the factors to be considered when looking at the processing/communications configuration.

30. Communications. There are three possibilities as to how the data (at whatever stage of processing) would be transferred from the satellite. First it could be relayed via communications satellites to a facility in Canada. The capacity required on the comsats would depend on the previous question of processing configuration but the SAR satellite would have to be able to track its relays.

31. Secondly the satellite could record its data and play it back when in range of the Canadian ground station. The great disadvantage here would be the delay before the satellite would be in range of the ground station and processing could start (approx 100 minutes max). Also recorders with high capacity at present have poor reliability.

32. The third option would be setting up multiple ground stations so that the SAR satellite would always be in view of at least one when it was viewing an area of interest and thus be able to transmit its data directly. These ground stations

would conduct/complete the processing of the data, sending only filtered tracks to the central facility. The number of ground stations would be dependant on the size of the desired coverage area. To be able to get real time information for everywhere north of 40N would require five ground stations of which 3 would be outside Canada. For this method the problem is the cost of multiple ground stations and the problems involved in locating them on foreign soil.

Power Considerations

33. The power requirements for this orbit are more extensive than RadarSat's primarily because the greater satellite altitude necessitates greater radar power. The radar will radiate when it over open ocean between 40 and 75N. The solar array must be sufficient to provide:

a. radar power plus housekeeping or

b. housekeeping power plus charge to the batteries sufficient for:

(1) radar operation for one eclipsed 40 to 75N transit plus

(2) housekeeping power for the longest possible eclipse.

34. For this 600 NM orbit a 40 to 75N transit takes .102 of the period and the longest eclipse is .324 of the period. Thus the charging requirement is .178 radar power plus .564 housekeeping power. Since radar power is an order of magnitude larger than housekeeping power the power requirement at b. above is smaller than at a. Therefore the duty cycle described here (2 x .102 or 20.4%) could be increased without enlarging the power supply. Battery capacity would limit how much of that increase could be during the eclipse.

35. The useful battery capacity required for a 20.4% duty cycle is .102R x P plus .324H x P where R is radar average power, H housekeeping power and P the period in hours. This is equal to .182R plus .582H where R and H are in W-hours. These power and battery requirements are end of life minimums. Reserves would have to be allocated for failures and degradation over time.

Submarine Detection Using SAR

36. Assuming SAR, or some similar sensor, can detect submerged submarines it could be possible to maintain a track of all submarines at sea within a designated area. The size of the area would sepend on the capability of the power generation/storage system. The revisit time would be dependant on the number of satellites deployed.

600 NM Orbit - One Satellite

37. For instance using only a single satellite with the orbit under discussion it would not be possible to have assured detection of submarines South of 56N if they were willing to accept the necessary restrictions on their speed and course. Thus those planning and executing a submarine's voyage would have to consider the relative effects on the mission of being detected or accepting these restrictions.

38. Detection Probability. As an example consider a submarine transiting from North Cape through the Faroes-Iceland gap to position 53N22W (i.e. just North of the main trans-Atlantic great circle route) and wishing to have the least chance of being detected. Until he reaches 56N the submarine has a .5 probability of being detected every two days if he follows the track of least detection probability. His probability of being detected is solely dependant on how long he takes to transit this area, i.e. his speed.

39. To find the probability of non-detection over a number of days one multiplies the probability over a single time period (two days in this case) by itself for as many time periods as required. Thus at five knots the target will spend 13 days North of 56N and his probability of non-detection is (.5) 13/2 or about one chance in 90. At ten knots this rises to one chance in 9 and at fifteen knots to one chance in four. Once at 56N the submarine can enter a "blind spot" and complete its transit undetected.

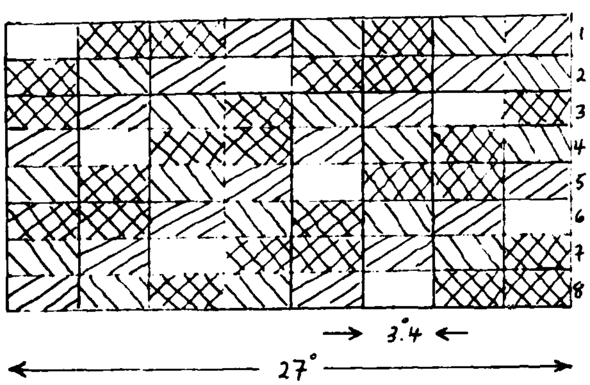
40. Clearly in the area where there is no blind spot a submarine is faced with the dilemna that at low speeds he is most vulnerable to detection by the SAR - equipped satellite while at higher speeds he is increasingly vulnerable to passive acoustic methods. Thus to an extent these two systems are complementary. It should also be borne in mind that the information from these two sensors is different in nature. The SAR would hypothetically give an accurate position and course but no speed for a submerged submarine, and the interval between updates is significant (hours to days depending on the constellation used). Passive acoustics give only a probability

area(up to thousands of square miles in extent) and an approximate speed and course but continuous contact can usually be maintained. The problems involved in localizing and tracking the two types of contact are thus quite different. For the SAR, time late on datum is critical to keep the search area within reasonable size but if achieved rapid localization is possible.

600 NM Orbit - Two satellites

41. As mentioned earlier the revisit time is primarily dependant on the number of satellites used. If we employ a constellation of two satellites using this orbit with the second satellite offset in longitude by approximately 6.8 degrees from the first there is a great improvement in surveillance capability. Fig 5 shows a time versus longitude plot (at 40N) of the possible coverage, with one satellite's passes indicated by diagonal lines and the second's by cross-hatching. There is no assured means of evading detection by this constellation in the area of interest. Because of this we can best assess the probability of detection by assuming that on any given day the target has an equal chance of appearing in any one of the eight swath widths within a 27 degree sector. Since seven out of eight of the swath widths could be viewed each day and there is one chance in two of a "potential" swath width actually being looked at on a given day the probability of detection per day (at 40N) is 7/8 x .5 = .438 and the probability of non-detection is therefore .563. By the same process the probability of non-detection per day at 56N and 68N are .417 and .125 respectively.

FIG 5
600 NMI ORBIT - 2 SAT POTENTIAL COVERAGE



42. Detection Probability. Looking again at the submarine transiting from North Cape to 53N 22W and assuming his speed to be five knots we find that he spends 5 days north of 68N, 8 days between 56N and 68N and 2 days between 53 and 56N. Thus the probability that he will make the transit undetected is $(.125)^5 \times (.417)^8 \times (.563)^2$ or virtually zero. At ten knots the probability rises to approximately one chance in 10,600 and at 15 knots to 1 in 540. Clearly by adding a satellite we have vastly increased the usefullness of the constellation.

43. This orbit is intended only a starting point for thought on naval uses of surveillance satellites. The assumptions of area and frequency of coverage were largely arbitrary and driven by what the Canadian RadarSat is being designed to be capable of. There are obvious disadvantages for the one satellite case with respect to probability of detection (particularily south of 56N) and ability to increase frequency of coverage on a given area.

44. To improve on these it was necessary to design a pattern in which the ascending and descending swaths on every day were immediately adjacent to each other giving the widest continuous coverage area possible. This would permit greater predictability in tracking (since position within a sector would no longer be significant) as well as increasing the speeds of the "blind spots" to unusable levels. Finally the altitude was raised such that four day coverage north of 30N was possible.

780 NM Orbit - One Satellite

45. This second orbit would require certain improvements in the radar power and data processing rate as compared to the 600NM orbit but has several advantages. In this case the inclination is 85 degrees and the altitude some 780NM. The greater altitude of the satellite widens the coverage swath to some 360NM of which approximately half can be viewed at any one time. The pattern of ascending & descending passes is shown in Fig 6. Each descending pass is immediately to the East of an ascending pass and the seperation between each such pair of coverage swaths is 28.8 degrees. The whole pattern "jumps" west 14.4 degrees per day. Note that this assumes each pass is looking at that section of the potential coverage area nearest the sub orbital point. Since the ascending pass can look further to the West and the descending pass further to the East each such pair has a potential coverage area approximately 720NM wide.

FIG 6
780 NMI ORBIT - 1 SAT ACTUAL COVERAGE

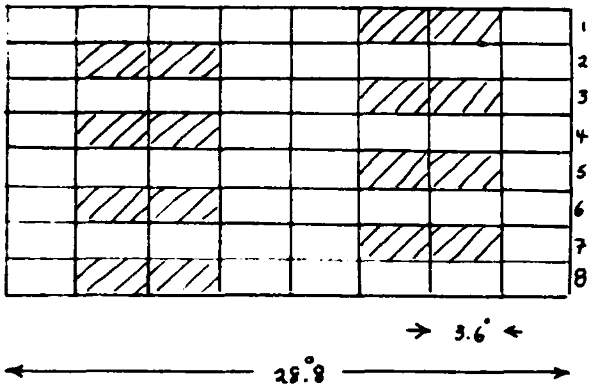
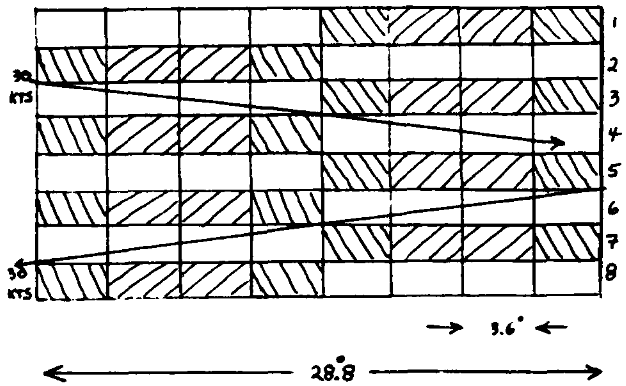


FIG 7
780 NMI ORBIT - 1 SAT POTENTIAL COVERAGE



46. Since each swath is wider than in the previous example the area which can be completely viewed every 4 days extends further south. Similarily the latitudes at which complete coverage is possible every three days and two days are also further South. The actual latitudes are:

every 4 days	30N	-	50N
every 3 days	50N	-	64N
every 2 days	64N	-	78N

47. <u>Coverage Area</u>. Figure 6 is a display of time in days versus longitudinal coverage of the swaths for the region 30-50N. While the pattern repeats itself every two days and appears to cover only half the area, it must be borne in mind that this shows all the swaths at their closest to the sub-orbital point. Looking at their potential coverage area (fig 7) we can see that everything North of 30N will fall within it every two days. Thus this orbit has the advantage that it is always possible to look at any given point twice as often as the nominal frequency. This has obvious potential for tracking a target after initial detection or keeping a particular area under closer surveillance.

48. <u>Detection Probability</u>. The probability of detecting a target using one satellite in this orbit is considerably better than the previous one. The only blind spots with this orbit rotate both East and West at 14.4 degrees per day. To stay in one of these the target would have to maintain 30 knots in the East-West direction. This can be discounted as unlikely in most naval scenarios. Using the same assumptions as previously we find the probability of detection per day to be .25 at 30N, .33 at 50N and .5 at 64N.

49. Recall the case of a submarine transiting from North Cape and passing between Iceland and the Faroes to arrive 100NM North of the trans Atlantic great circle route at position 53N 22W. Transiting at five knots he will spend eight days N of 64N and 7 days between 64 & 53N. Thus the probability of his not being detected while transiting is $(.5)^8 \times (.67)^7$ or about one chance in 4200. At ten knots the probability rises to $(.5)^4 \times (.67)^{3.5}$, about 1 chance in 65, and at 15 knots to about 1 chance in sixteen.

50. The disadvantages to this orbit as compared to the previously described one are that since it is operating at a greater range from the earth its radar must be approximately 220% more powerful (and hence its power supply system also) and since it views a greater area the raw data rate is greater by some 10%, necessitating higher processing capacity to stay in real time. Also being at a higher altitude the satellite is in an area of higher radiation and requires additional hardening against this. Against these

disadvantages this orbit provides a greater frequency of coverage over a wide area, greater probability of detection and more flexibility in the coverage patterns.

PART III - CONCLUSIONS

51. Allies. There are several points of a general nature which apply to naval surveillance using satellites. First any satellite surveillance system will look at every point on the earth's surface between its most southerly and northerly excursions (ie its inclination) on a regular basis. Therefore any Canadian system would be able to look at extensive areas that may be of only peripheral interest to Canada but of significant interest to one or more of her allies. In the particular case of a submarine surveillance system the USA would be especially interested as they would probably view the data from such a Canadian system as a potential danger to their nuclear submarine fleet, particularily their SSBNs. They will probably wish to have some control over the security of the information and this issue will likely have to be faced early in any Canadian project.

52. Other Sensors. Secondly during work on this paper it became evident that unless large constellations of satellites are used SAR, or any sensor giving similar data, would supplement, not replace, existing submarine surveillance systems due to the relativly infrequent revisit times. This being the case the orbit, hardware and processing for any satellite system must be designed taking into account this need to act in conjunction with more conventional surveillance systems including acoustic ones. The principal operational question is how best to organize the satellite constellation to produce data which effectively complements information from other sources. Relating to both the previously mentioned points is the fact that the USA controls precisely those sources of information (ie large area submarine surveillance) most needed to complement a satellite constellation. Therefore there is an argument to be made that both the US would want and Canada would need American participation in such a system.

53. Design Questions. There are a number of questions which effect the orbit which must be answered early in any design process. Among these, what is the expected target's speed? (ie what blind spot rotation rate is needed?). How great is the need to be able to track a target on a regular basis? What is the maximum nominal revisit time allowable bearing in mind that for a given orbit this will vary inversly with latitude? Is there an area (ie latitude) of particular importance? These will all drive the orbit design which should in turn drive hardware and processing considerations.

54. Finally the raw radar information from a SAR can be processed in various ways depending on the type of target being sought. This will probably be true of any sensor used. Thus the same raw data can be manipulated for different purposes, both military and civilian, making SAR an inherently multi-purpose sensor. For a Canadian system this presents advantages in that costs could be shared to same extent with a non-DND agency or agencies. Compromises might have to be made with respect to orbit but there is the possibility that the security sensitive hardware, procedures and output could be confined to a completely seperate military ground processing facility thereby largely sidestepping the problem of compromising classified information due to civilian involvement.

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DYNAMIC SPACECRAFT SIMULATORS IN MILITARY SPACE GROUND SYSTEMS

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ABSTRACT

Simulators have long been used in training situations to provide hands-on experience without risking expensive real systems. The most common example is in aircraft flight training. It has been OAO Corporation's experience that the same principles can be applied on a much more modest scale to expedite spacecraft ground system integration and operator training. The authors

The purpose of this paper is to outline some of the uses of simulators in the military space ground system environment, present some indicators which aid in determining when a simulator can be beneficial and illustrate features of appropriate simulator design. We validate these points by drawing on six years experience in providing space vehicle and operational simulation aids to NASA, USAF and commercial satellite control centers.

I. INTRODUCTION

The dynamic spacecraft simulator is a mature yet flexible concept which has been utilized in a wide range of NASA and DOD programs. Spacecraft simulators are highly regarded in all of their applications and can be adapted to the needs of any spaceflight program. The remainder of this paper presents a detailed description of OAO Corporation's approach to simulator design and applications and discusses the ease with which the spacecraft simulator requirements can be defined.

II. SIMULATOR APPLICATIONS AND BENEFITS

A dynamic spacecraft simulator is an optimal mechanism for exercising ground based activities and can represent a demonstrable cost savings over the course of a mission. Some of the more salient applications include:

- Training
- Operations/data base validation
- Contingency planning/workaround development
- Mission rehearsals
- Pre-launch checkout/validation
- Software checkout/qualification

Each of these simulator functions is described in more detail in the following paragraphs.

As a trainer, the spacecraft simulator can provide valid replication of real spacecraft performance with student interaction, yet it totally insulates the live vehicle from inadvertant contact with training operations. Further, for a new spacecraft design, it provides the only means for this level of on-the-job-training (OJT) prior to launch. The simulator also provides an ideal tool for testing operator contingency proficiency. Expected or predicted anomalies can be synthesized and repeated. It can also be used in the certification/recertification of operators and in more effective OJT. Finally, should the operational environment change due to spacecraft changes, equipment degradation or failure, for example, the simulator offers a unique and efficient method of implementing real-time training.

Another application of a spacecraft simulation is the validation of operations and data base software. Parameters such as operations language procedures, display formats, and data base values can be verified as accurate prior to use in real-time operations. Moreover, non-nominal paths in operations language procedures, especially those responsible for alarm messages and emergency mode reporting, can be exercised and validated.

In contingency situations the dynamic spacecraft simulator has proven indispensable in anomaly analysis and recovery planning. During anomalous conditions the simulator can recreate observed problems and test and evaluate workarounds. It can also be used to assess controller responses in terms of accuracy and swiftness of action. In the critical moments of spacecraft emergency conditions, the simulator offers the opportunity to examine the impact and implications of a correcting maneuver without endangering the health and safety of a live spacecraft or, ultimately, losing the vehicle entirely. NASA's TIROS-N controllers, trained on a dynamic simulator were able to contend with

an early orbit sudden hydrazine leak as well as later on-board computer (OBC) anomalies while preserving both on-orbit test schedules and maintaining delivery of payload products.

A natural extension of the training and contingency simulation capabilities is the rehearsal of mission requirements since both normal and anomalous conditions can be easily replicated. This can be especially beneficial for critical launch pad testing which is often extremely time limited. Further, a launch handover operation is a very singular operational activity for which a simulator provides an efficient and economical means of training and rehearsing by stimulating resident data base parameters.

Finally, ground system software which participates in the same environment with the simulator can effectively be qualified since it can easily provide or generate:

- Nominal data
- Unique application data
- Perturbed data
- Test patterns

Stress testing of ground system software is easily provided by a simple extension of the simulator capabilities. Utilization of OAO Corporation's Defense Meteorological Satellite Program (DMSP) Block 5D-2 Simulator by the Air Force resulted in shortening the ground system integration cycle and cut crew training time by more than half while maintaining proficiency.

Inherent to the applications of a spacecraft simulator are significant benefits to the operational environment of the mission. Some of the more salient benefits include:

- Increased reliability of the controllers
- Increased efficiency of the controllers
- Maximized utilization of operational resources
- A resident integration validation and verification (IV&V) capability
- Possible extension of spacecraft life through anomalous conditions

Although a dynamic Space Vehicle (SV) simulator is not the only tool available for some of the previously mentioned applications, it offers substantial advantages over the other options as indicated in figure 1.

The tape replay refers to digital recordings of actual spacecraft data played through appropriate elements of the ground system. One major drawback of this approach is the need for an operational spacecraft system. The scenario generator on the other hand has very limited application and allows little if any dynamic capability.

CRITERIA \ TOOL	TAPE REPLAY	TELEMETRY SIMULATOR	SCENARIO GENERATOR	DYNAMIC SIMULATOR	LIVE SPACE VEHICLE (SV)
USES					
GROUND SYSTEM TEST	✓	✓	✓	✓	
DATA BASE VALIDATION	✓			✓	✓
OPERATIONS VALIDATION		✓	✓	✓	
TRAINING		✓	✓	✓	
CONTINGENCY ANALYSIS	✓			✓	
MISSION REHEARSAL	✓	✓	✓	✓	
FLIGHT CODE/CMD CHECKS				✓	✓
PERFORMANCE					
ACCURACY	H	H	H	H	H
FIDELITY	?	L	L	H	H
REPEATABILITY	H	H	H	H	H
FLEXIBILITY	L	L	M	H	L
ACCESSIBILITY	M	L	M	H	L
OPERABILITY	M	L	M	H	L
INTERACTIVE	NONE	L	M	H	M
OTHER CONSIDERATIONS	REQUIRES EXTENSIVE PREPARATION TO MAKE TAPE. TAPE THEN IS FROZEN.	FUNCTIONAL INTERACTIONS ARE NOT MAINTAINED	REQUIRES A PRIOR KNOWLEDGE OF OPERATOR RESPONSES AND EXPECTED SV PERFORMANCE	FUNCTIONALLY ACCURATE. PERMITS SPONTANEOUS RESPONSES TO BE STUDIED	SAFETY OF SV WILL DICTATE DEGREE OF OPERATOR INTERACTION

Figure 1. Comparison of Simulation Tools

III. THE SIMULATOR ARCHITECTURE

The generic OAO Corporation simulator architecture is illustrated in figure 2. As represented, simulation software is executed in a host processing system. Standard interfaces provide access to high-speed disk storage, magnetic tape storage (for disk back-up and canned simulation scenario support), a line printer (for hard-copy telemetry and command records used in off-line analysis), and the simulator control and display. In general, a simulator can be run either in an off-line or on-line configuration. The off-line system is useful for debugging and testing purposes. It may run in a real-time or non real-time mode. Simulator control is from the Simulation Director's console. The on-line system runs in real time and is generally used with some sort of graphics capabilities. The OAO simulator

accepts commands, processes them, and produces realistic telemetry from the various spacecraft subsystems. In the normal, on-line mode of operation, the simulator receives commands from and delivers telemetry to an Operations Control Center (OCC). Intermediate output and telemetry can also be routed to the printer. The simulation process is data base driven and is dynamically updated.

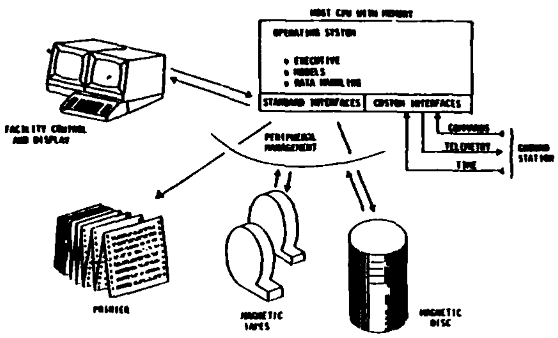

Figure 2. Spacecraft Simulator Concept

The simulator software structure is shown in figure 3. The basic software modules consist of an executive which provides simulation control, operator interface, and initialization; a data base containing all simulation parameters and files; and the various spacecraft subsystem models including thermal, power, telemetry and command, orbit and attitude control, and spacecraft state and environment. The relationship of these software modules with the host system and each other is represented in figure 4. Each of these modules is described further in the following paragraphs.

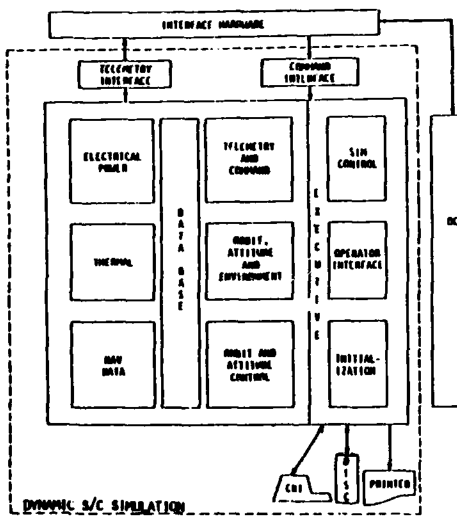

Figure 3. Spacecraft Simulator Software Structure

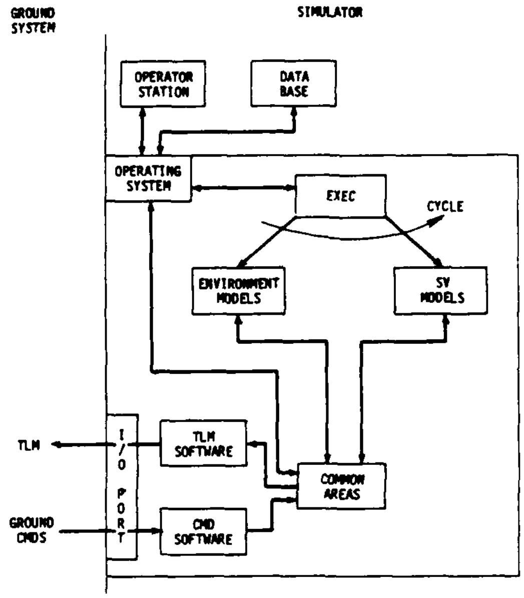

Figure 4. Dynamic Modeling Architecture

The Executive Subsystem

The executive is typically one of the more sophisticated subsystems in a simulator. Functionally, the executive controls the scheduling of the tasks through three phases: initialization, execution, and termination. During the initialization phase, user-supplied parameters are read in and used to set up the initial configuration of a simulation run. This initial configuration can be changed during the course of a run by operator intervention. Otherwise, the initial conditions remain in effect throughout the run.

The initial conditions include selecting an on-line or off-line run, a real-time or nonreal-time run, and other features to be included such as graphics, plotting, checkpointing, and refreshing.

During initialization each routine selected is executed once to perform any initialization necessary. When the execution phase is entered, the simulator continues cycling until the desired stop time is reached or until a stop command is entered from a control console.

All routines are executed once more in the termination phase to give each a chance to close down. During the termination phase a call count summary is usually printed showing how many times each routine was executed. A log sometimes is produced showing any timing problems that occurred during the run and any error messages that developed are also printed.

During the execution phase the simulator can be in either one of two modes, normal or idle. Either mode can be specified as the initial mode

of the simulation run. During the normal mode the simulator begins cycling, the simulation time advances, and all modeling and communication routines are called. Idle mode is used to temporarily stop the simulator, update any parameters desired, and then allow the simulator to continue with a new set of conditions in the normal mode. During the idle mode only the communications routines are executing. The simulation time is stopped. Commands continue to be received and executed and telemetry is fabricated and transmitted. This allows the user to modify spacecraft conditions by changing simulator variables.

The functional flow of the executive subsystem is characterized in figure 5.

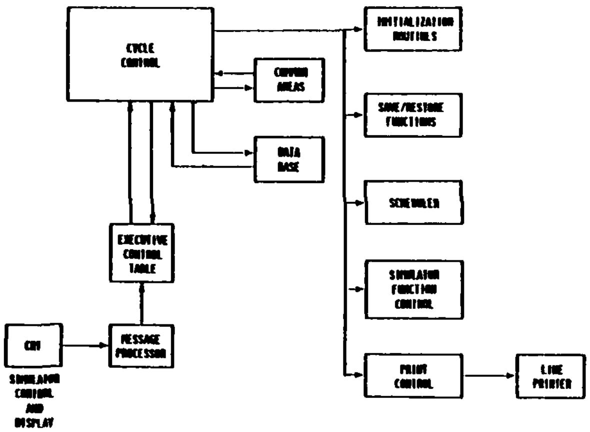

Figure 5. Executive Subsystem Overview

Spacecraft Subsystem Models

The various spacecraft subsystem models may be configured to interact with the rest of the simulator as indicated in figure 6. Each of these models depend heavily on interaction with the data base. The degree of analytical representation, or fidelity, of each model is generally unique for each mission. The simulator best illustrates its flexibility with the ease by which unique mission profiles can be constructed through access to models of assorted fidelity levels. Examples of parameters typically modeled in each subsystem are presented in Table 1.

IV. TRADES AND CONSIDERATIONS

There are many considerations in the design of dynamic spacecraft simulators. There are four significant issues however, which drive the requirements and specifications of a simulator to an appreciable level of detail. The issues are:

- The level of fidelity
- Timing trade-offs
- Implementation approach
- Hardware/software trade-offs

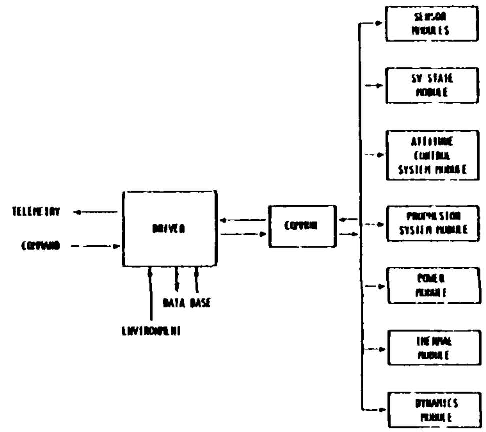

Figure 6. Spacecraft Modeling Overview

Table 1. Typical Spacecraft Subsystem Model Parameters

TELEMETRY AND COMMAND	SPACECRAFT STATE AND ENVIRONMENT	ORBIT AND ATTITUDE ATTITUDE CONTROL
RECEIVER AGC's	ORBITAL EPHEMERIS	MODE SELECTION
SECURE/BYPASS MODES	SUN, MOON POSITIONS	REACTION WHEELS CONFIGURATION AND CONTROL
ANTENNA SWITCHING	EARTH'S MAGNETIC FIELD	JET SELECTION AND CONTROL
BIT RATE CHANGES	SOLAR PRESSURE	MAGNETIC COIL TORQUES
TELEMETRY FORMAT CHANGES	DAYLIGHT/ECLIPSE	ATTITUDE BIAS
AUTHENTICATION		YAW SENSORS
		EARTH SENSORS/SUN SENSORS
		NUTATION DAMPER
		JET WATCHDOG
		PROPELLANT TANK TEMPERATURES AND PRESSURES
		LATCH VALVES
		GAS STORAGE TANKS
POWER	**THERMAL**	**SPECIAL SUBSYSTEMS**
SOLAR ARRAY SENSORS	SOLAR HEATING	PROCESSOR LOADS
SOLAR ARRAY CONTROL ELECTRONICS	ECLIPSE COOLING	PROCESSOR CONTROLS
SOLAR ARRAY ACTUATION		PROCESSOR DUMPS
BATTERIES	SUBSYSTEM POWER DISSIPATION	FREQUENCY STANDARDS
SHUNT DISSIPATORS	HEAT FLOW	FREQUENCY SYNTHESIZERS
REGULATORS AND CHARGES	THERMOSTATS	MODULATORS
CONVERTORS	LOUVERS	POWER AMPLIFIERS
LOAD CONTROL	HEATERS	FILTERS
LOAD SHED TIMERS	RADIATORS	ANTENNAS
	CATALYST BED TEMPERATURES BATTERY TEMPERATURES	

Each of these considerations are discussed below.

Level of Fidelity

The issue of model fidelity is critical to the applicability of the simulator for its various uses. It appears as a trade issue in that the degree of fidelity will greatly affect the necessary analysis, model complexity/size, and timing, which of course influence cost, schedule, and choice of host computer. A systematic approach to accurately determining the fidelity level for each model begins with identifying the simulator characteristics and outputs subject to variable fidelity. Next, the simulator requirements are analyzed with respect to fidelity level, and, finally, simulator models are qualified according to fidelity level.

OAO partitions its models into four levels. The simplest is the static model (level 1) in which a user may select values for different telemetry points which remain constant throughout the simulation time. More complex is a bilevel model (level 2) consisting of user-selected values based on the spacecraft's condition (e.g., dark/light) and equipment status (e.g., on/off). Increasing in complexity, level 3 is an equation solver or function generator with which the user selects varying values for different telemetry points. For example, solar array temperature can have two values (bi-level) depending on dark and light conditions. Or, it can be modeled as level 3, where solar array temperature will rise exponentially between two temperatures, depending on the spacecraft's condition. Level 4 is the most complicated, and is the dynamic model. It represents interactive real-time computed values individually modeled in different modules, and is the product of several inputs (spacecraft's position, solar array position, total power consumptions, etc.). All of the telemetry points usually fall in one of these four categories. Table 2 summarizes the modeling classifications.

Table 2. Modeling Classifications

LEVEL		DESCRIPTION
1	STATIC:	SELECTED PARAMETER VALUES WHICH REMAIN CONSTANT THROUGHOUT A SIMULATION
2	BILEVEL:	DISCRETE OR ANALOG VALUES WHICH ALLOW BINARY DECISIONS (e.g., ON/OFF, LIGHT/DARK, 0/1, ETC.)
3	EQUATION:	CONTINUOUS RANGE OF PARAMETER VALUES DERIVED FROM AN EQUATION (e.g., RAMP, STEP, LOG, ETC.)
4	DYNAMIC:	EMPLOYS NUMERICAL INTEGRATION TECHNIQUES AND MULTIPLE PARAMETERS IN PROVIDING REAL, DYNAMIC SIMULATIONS.

An important fidelity issue is the accuracy of the dynamic models. These models are always analytic in nature, make use of implicit or explicit integration (i.e., are from solutions of differential equations or require minimal integration), and show variation at system bandpass or higher frequency. Thus, the model implementation represents serious implications for core and cycle time.

It is necessary to always considers the degree of accuracy needed for these models in terms of their use in training, software validation, and post launch anomaly investigation. Each of these respectively, usually require a more sophisticated model run at higher cycle frequencies. OAO establishes model complexity in terms of core and percentage of computer time per cycle.

Timing Considerations

The generation of simulation time and its relation to real time, as understood by the ground system, is always a key issue. The issue is the consistency of time within the simulator and between the simulator and the ground system.

In general, the simulator time will not be actual time due to training-specific situations and the use of checkpointing and refreshing. Nevertheless, the simulator time, as understood by the ground must maintain internal consistency with the ephermeris and spacecraft clock.

Implementation Approach

The salient implementation approach considerations include a) what ground system interfaces will be necessary and in what way should they be represented (i.e., emulation vs. real), b) whether the simulator shares a host with other processing functions or is resident in its own host, and c) the scope of the simulated application. Each of these issues represents some trade involving software development, hardware sizing, operational timing, and, of course, cost. In the case of the NASA Solar Maximum Mission (SMM) Simulator, a shared host (IBM 360/65) with special interfaces (PDP-11/10 and a DX-11 interface unit) and peripherals (interactive graphics facility) resulted in an efficient and highly flexible dynamic simulator. Similarly, with NASA's Landsat-D Simulator all simulation was performed by software. At the other end of the spectrum is the Air Force's DMSP Block 5D-2 Simulator which utilized a dedicated host, custom hardware and a real OBC to accomplish the facility objectives.

Hardware/Software Trades

In general terms, the trade between hardware and software in a simulator design spans a spectrum of a total hardware implementation to a total software simulator with a relative mix of each

falling in between. Not surprisingly, the two are proportionally related since software scope increases as the amount of special hardware decreases. Table 3 qualitatively compares some of the characteristics considered in hardware/software trades. Figure 7 is an example of trade comparisons generated by OAO for five alternatives in the Air Force's DMSP Block 5D-2 Flight Vehicle Simulation Facility (FVSF).

Table 3. Sample Hardware/Software Trade Characteristics

CHARACTERISTIC	ALL HARDWARE	HARDWARE/ SOFTWARE MIX	ALL SOFTWARE
RELATIVE FIDELITY	HIGH	HIGH	MEDIUM
HARDWARE SCOPE	HIGH	MEDIUM	LOW
SOFTWARE SCOPE	LOW	MEDIUM	HIGH
MAINTAINABILITY	LOW	HIGH	HIGH
OPERATION	DIFFICULT	FAIRLY SIMPLE	SIMPLE
ANOMALY SIMULATION	DIFFICULT	LIMITED	SIMPLE
RELATIVE SIM SPEED	SLOW	MEDIUM	HIGH
RELATIVE COST	HIGH	MEDIUM	LOW

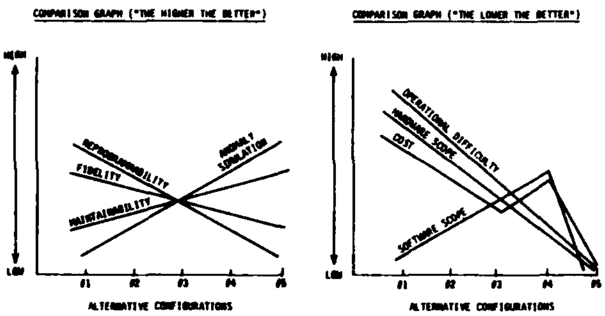

Figure 7. Hardware/Software Trade Comparisons

Each of these issues however, cannot be considered individually but, rather, there is an interplay between the various factors. For example, model fidelity may require a host core size and speed which would influence host selection, and the host selection in turn will influence interface design.

All issues require, therefore, an integrated review before a preferred solution is finally established.

V. OPERATIONAL STRATEGY

Operational strategy addresses the question of how the simulator will be used and what special features will enhance its utility in the ground system over the life of a mission. Typically, simulators grow on the users in that the initial objectives are rapidly fulfilled and new capabilities are perceived as the mission develops. This places a premium on user-friendly operating concepts and on automated intialization and support utilities. For example, consider a typical training scenario.

Prior to the training session, the simulation operator, or trainer, would construct a command schedule defining key elements of the session such as ephemeris, initial spacecraft state and equipment status, data acquisition times, etc. He does this with the simulator in a stand alone mode and by building on existing data bases and schedules. When the session is run,the simulator operates under control of the schedule and responds to real time inputs from the ground system, leaving the trainer free to observe and advise the students. The trainer still has access to the schedule and the simulator data bases so he can insert unplanned anomalies or take checkpoint data throughout the session. At the end of a session the new checkpoints can be used to repeat selected portions without requiring the entire schedule to be redone. Similarly, the history data can be played back for analysis of significant items or to serve as an illustration of a specific training issue.

Scenarios such as this can also be postulated for ground system validation, anomaly investigation and all the other potential uses of the simulator. The unifying theme is that the simulator is intended to be a functional representation of the orbiting spacecraft.

Real-Time Operation

Simulators can operate in real time either with or without inputs from the ground system. Real time refers to events that are supported in the proper wall clock time in the operational environment rather than strict logic speed synchronism. For both modes of operation, telemetry outputs and command inputs are provided and accepted, respectively, at the same rate as they would for an operational spacecraft (i.e., real-time simulation).

Stand Alone Operation

Simulators also usually incorporate the capability to operate in stand-alone mode without inputs from the ground system. In this mode, the simulator system consists of the simulator host computer with its associated peripherals and special hardware. The host real-time clock is used to generate the interrupts necessary for real-time cyclic simulation functions.

Commands are input using a host CRT and telemetry is available for display on a host CRT. No connection to the ground system is necessary for this operational mode.

Schedule Control

Simulator control can be provided by the use of prepared schedules. These schedules consist of commands with associated time tags having a nominal 0.5 second granularity. Schedule commands can be either simulator control, model parameter modification statements or spacecraft commands. The schedules are built in an off-line mode and stored on disk without interfering with ground system operation. The method of a schedule build considers the ease of operator interaction. During a simulation run, the schedules may be called from the disk schedule file and activated by a trainer command. These inputs can also be accepted individually from the trainer position in real-time.

Checkpoint/Restart/Idle

Checkpoint, restart, and idle are extremely useful capabilities which are incorporated into most simulators. A checkpoint is the saving of current facility parameters such that the saved file is sufficient to restart the run from the time the checkpoint was taken. The effect of a checkpoint operation is to record in a user-specified file a complete set of data representing the current state of the system. As a minimum, this data includes, a) the system database, b) the names of all the data files currently supplying data to the system (e.g., schedule files), and the current read position within each file, c) all data necessary to completely represent the state of each model, and d) the total system configuration information. Time is halted while a checkpoint file is being created or reloaded into the facility.

Restart is initializing the facility utilizing a previously stored checkpoint file. In particular, the restart action includes a) verifying, via checksumming or similar techniques, the validity of the checkpointed data, b) restoring the system database and any other data needed to represent the state of each model, c) interacting with the system operator to obtain the additional data files (schedule files, etc.) that are needed, d) initializing I/O logic to begin reading at the proper position in each file, and e) verifying that the system configuration is the same as, or is compatible with, the configuration on which the checkpointed data was generated.

Idle is interrupting the flow of time for the purpose of examining or modifying specific data without creating a checkpoint. Analog and digital telmetry flow are maintained while the facility is in idle mode, but the data values are static.

Anomaly Injection

Another important capability of a spacecraft simulator is to provide a means for anomaly injection. Anomaly injection is provided under direct control of the trainer. The anomalies are entered directly from the trainer console, or by use of prepared schedule files. The anomaly injection procedure does not interfere with the real-time update of simulated data.

Anomalies usually represent one of three types of errors: uplink errors, downlink errors and spacecraft subsystem anomalies. The uplink error may include either a specified bit error rate or trapping of a specified command. Downlink errors may be either incorrect sync patterns, incorrect parity words or the complete loss of data. The spacecraft subsystem anomalies may consist of subsystem failures chosen with the following criteria in mind:

- Probabilistic subsystem failures from prior spacecraft performance data
- Anomalies for which ground system personnel reactions are significant
- Anomalies which are precursors to more serious malfunctions

Truth Data

Truth data is often accessible to the simulator trainer independent of the telemetry processing by the ground system. This data consists of both telemetry data and non-telemetered parameters which are of importance in observing simulator operation.

Clock Synchronization

A mechanism is usually provided in the simulation facility for synchronizing the clocks to that of the ground system. During a real-time run, all time dependent processes are synchronized to within one nominal time update step.

History Tape

A valuable capability generally provided is the ability to generate a history tape of the telemetry data and command activity during simulation operations.

VI. SUMMARY

Spacecraft dynamic simulators have been shown to provide many benefits to military space ground systems. Beneficial applications include training, operations validation, contingency planning and workaround development, mission rehearsals and ground system checkout and qualification. The simulator architecture presented is based on a real-time implementation of dynamic closed-loop spacecraft and environment

modeling. An approach to the design and operational trade-offs important to any simulator implementation was presented, including a level of fidelity analysis methodology. Finally, various operational strategy issues were presented and discussed. OAO believes that a dynamic space-craft simulator provides a valuable capability for military space ground systems and furthermore can provide these benefits with a positive benefit/cost ratio over typical system life cycles.